PHYSICS
The *Higgs* at Last?

PSYCHOLOGY
The Wisdom of *Psychopaths*

ENVIRONMENT
Ecosystems on the Brink

SCIENTIFIC AMERICAN

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OCTOBER 2012

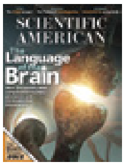
The Language of the Brain

How the world's most complicated machine processes and communicates information

SPECIAL REPORT

State of the *World's Science* 2012

ON THE COVER



The way billions of cells in our brains communicate to produce the image of a rosy sunset or the sound of Beethoven's Fifth remains somewhat of a mystery. The timing of signaling turns out to be key. Several neurons firing at the same time in the eye, for instance, can efficiently transmit messages to the visual-processing center at the back of the brain. Image by Kenn Brown, Mondolithic Studios.

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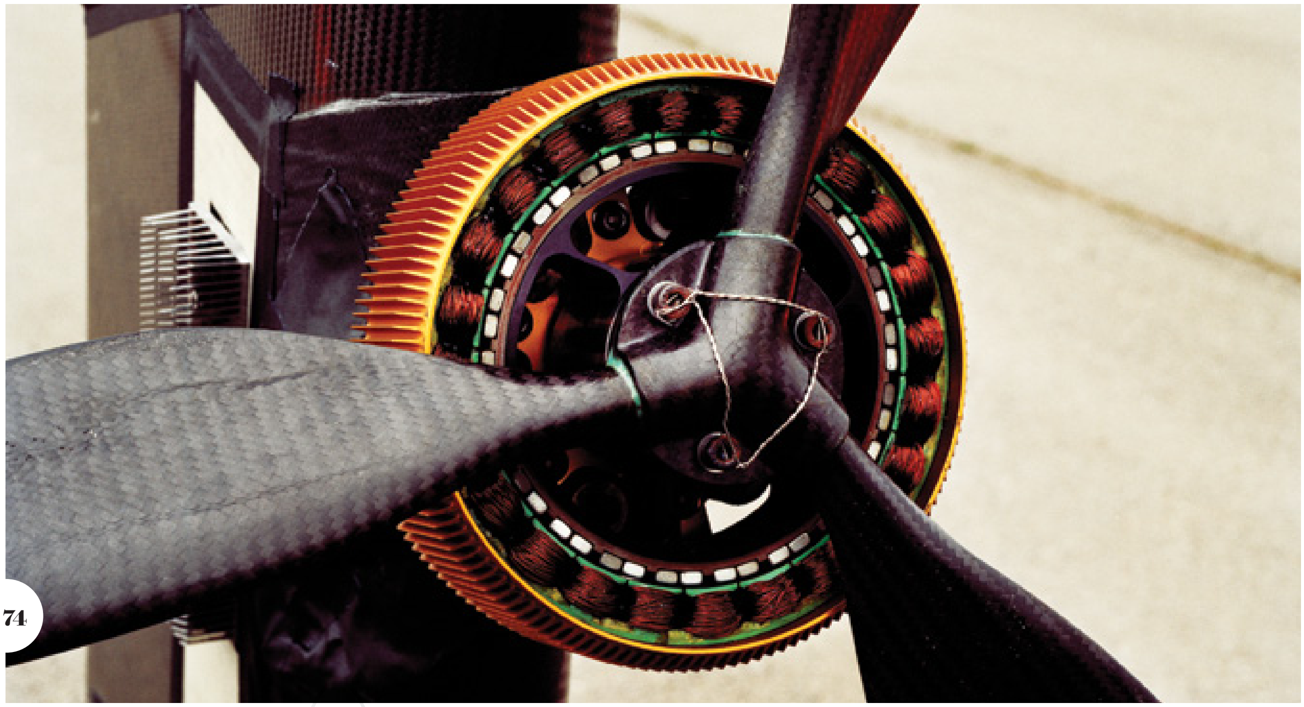
October 2012 Volume 307, Number 4



FEATURES

Photograph by Jake Stangel

9

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Wheels Down for Curiosity
Go inside the control room to relive the hair-raising landing of NASA's massive Curiosity rover. See what comes next as it sets off in search of potentially habitable environments on Mars. *Go to www.ScientificAmerican.com/oct2012/curiosity*

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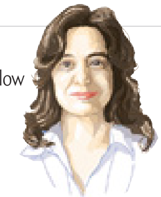
Mariette DiChristina is editor in chief of *Scientific American.* Follow her on Twitter @mdichristina



A Global Affair

"HOW MANY SCIENTISTS ARE IN YOUR GOVERNMENT?" People asked me all sorts of things when I visited Moscow last year, but that simple question, and its expectation that naturally there should be many, made me pause. I knew of Russia's multimillion-dollar "megagrant" investments to encourage expatriate researchers to work in the country and the around $11 billion set aside to gin up nanotechnology businesses. Visiting Doha, Qatar, I learned about that country's pursuit of a "knowledge-based economy" and its aims to foster solar energy for desalination as well as telemedicine. At the annual Lindau Nobel Laureate Meeting in Germany, I saw nearly billboard-size portraits of science's eminent figures, celebrity-style. Clearly, many nations see science as their ticket to a better future.

I reflected on my own country's uneven relationship with science. Technological innovation is responsible for half the U.S.'s economic growth since World War II. It has been the engine of our modern prosperity. Yet today we are faltering in critical areas of science, technology, engineering and mathematics (STEM) education and in maintaining sufficient budgets for research. It was high time, I decided, that the U.S. started focusing on what matters.

With that ambitious goal, we began work on this issue's special report, "State of the World's Science." Executive editor Fred Guterl has organized an array of stories on the critical themes in global science today, from the rise of China to the manufacturing power of Germany to the best ways to encourage individual scientific achievement. Informational graphics highlight such features as research spending and the number of papers published in select journals. Turn to page 28 for the start of the section. As I hope you will agree, the result is thought-provoking—and inspiring. SA

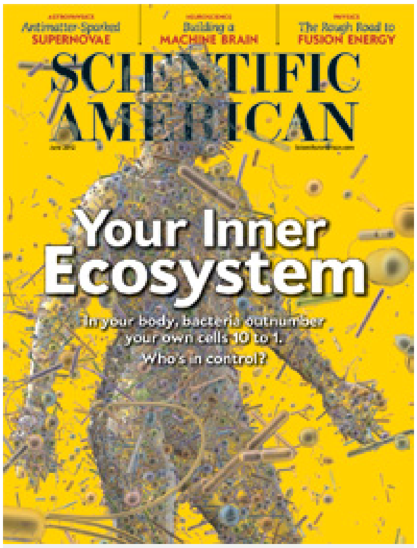
Swaziland Scientists

At the second annual Google Science Fair awards event, I had the privilege of bestowing trophies on the 14-year-old winners of the *Scientific American*–sponsored Science in Action Award. The award, for a project that helps a community with a social, health or environmental issue, is $50,000 and a year of mentoring to continue the work. Bonkhe Mahlalela and Sakhiwe Shongwe developed a simplified hydroponics system that uses 90 percent waste materials (cardboard boxes, sawdust, chicken manure) and improved productivity in crops tested by 140 percent. Believing that education and simple science can create self-sufficiency, they plan to use part of their prize money to train Swazi subsistence farmers. *—M.D.*

WHO'S WHO: *Front row:* Mariette DiChristina, winner Bonkhe Mahlalela. *Back row:* Sade Kammen, mentor Daniel M. Kammen, winner Sahkiwe Shongwe, mentor T. H. Culhane, teacher Titus Sithole.

Photograph by Andrew Federman; Illustration by Nick Higgins

editors@sciam.com



June 2012

CYBORG HUMANITY

I was struck that of the "important ethical issues" Henry Markram refers to regarding building a completely simulated human brain in "The Human Brain Project," the only one he raises is that of a superintelligent nemesis being created. He does not appear to consider the ethical obligations we would have toward the mind we had created. I worry about the precarious humanity of the minds we would create and about the humanity of the researchers who could, with the touch of a button, give a being with memories and an expectation of the future—if this all works as Markram hopes it will—autism, schizophrenia or a progressively degenerative disease. Who will turn off the simulation when the virtual mind begs them not to?

Robert A. Rushing
University of Illinois at Urbana-Champaign

Markram glosses over the key potential benefit of the project: understanding the human brain may allow us to augment intelligence and eventually create superintelligent nonbiological humans.

It also raises a key metaphysical question: If the simulation of the human brain is deterministic, how can it have free will? Or is it impossible to fully simulate human cognition on a deterministic machine?

Dmytro Taranovsky
Woburn, Mass.

"I worry about the humanity of researchers giving simulated human brains mental disorders."

ROBERT A. RUSHING *UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN*

SUPERNOVA MYSTERY

Avishay Gal-Yam's "Super Supernovae" discusses how stars once thought to be too massive to explode have resulted in supernovae more powerful and longer lasting than any previously observed.

Gal-Yam describes how the production of electrons and positrons removed such stars' supporting pressure of gamma rays, leading to their sudden collapse. But he didn't say what happens to the positrons. Wouldn't they collide with the electrons, be converted back to gamma rays and thus restore support for the star?

Also, do gamma rays from a positron-electron reaction have a characteristic wavelength that can be observed?

David Smith
via e-mail

GAL-YAM REPLIES: Indeed, positrons produced in the hot core of the star will eventually annihilate with electrons and produce pairs of gamma rays with a particular energy equal approximately to the rest mass of the electrons. This process takes time, however, which means that at any given point, the energy (that was previously completely carried by photons) will now be distributed between photons (which provide pressure) and electrons and positrons with energy dominated by rest mass (which do not). Thus, the overall pressure drops, the core contracts, and so on.

The gamma rays produced by electron-positron annihilation do have a characteristic energy (511,000 electron volts, or 511 KeV), but they are unobservable because the envelope of the expanding star is not transparent; the gamma rays interact with electrons and ions in the outer layers of the expanding, exploding star and are converted to lower-energy photons, which we eventually can observe as light.

PUBLISH AND PERISH?

"Waiting to Explode," by Fred Guterl, addresses the controversy over publishing two recent studies on the development of H5N1 flu strains that are transmissible among mammals (both studies have since been released). As a scientist, I initially felt it was necessary for all the H5N1 bird flu results to be released: publications allow other scientists to continue projects, and researchers have a responsibility to communicate their data to other scientists. After careful consideration, however, I now feel that submitting all the data was a mistake. The results from this project could help terrorists perfect an airborne delivery system to infect humans.

The solution to this problem would have been to publish some of the scientific findings but restrict the key elements—namely, precisely how to make changes to the viruses that would create an airborne entity. These undisclosed methods could have been shared on a case-by-case basis among researchers, which would have allowed for the continued examination of data among responsible parties trying to enhance public health.

Publishing a redacted form of the manuscript would have satisfied the need for scientists to exchange general data to fight any future pandemic and yet protect security needs. Unfortunately, these changing times will force us to reevaluate and redesign our traditional approach to sharing scientific discoveries in favor of the greater good.

Claude E. Gagna
New York Institute of Technology

TWO-FACED BUG

In "The Ultimate Social Network," Jennifer Ackerman writes about the "benefits" of the bacterium *Helicobacter pylori* on the digestive system and its possible role in controlling obesity. She describes *H. pylori*'s maligned status in the medical world as a "nasty rap" because of its role in causing peptic ulcers.

Ackerman neglected to mention *H. pylori*'s role in stomach cancer. Whereas

only 1 to around 2 percent of *H. pylori* patients develop gastric cancer, *H. pylori* infection makes you nearly six times more likely to develop the disease.

This hits close to home for me. My father, brother and I were diagnosed with *H. pylori,* and I was found to have stage IV gastric cancer. Scientific research into the complex relation between *H. pylori* and humans is critical. Nevertheless, it is important to remember that this bug is a killer.

Mhari Saito
Shaker Heights, Ohio

INSPIRING INSECT

After reading Backyard Brains co-founder Greg Gage's description of his company's SpikerBox kit in "When Cockroach Legs Dance" [Advances], I immediately found a YouTube video of Gage hooking it up to his iPhone. His device allows you to hear the neural activity in a cockroach leg that is made to dance. I was amazed and thought how much I would have liked to use it in my classroom.

I taught seventh grade life science for 40 years and always believed it was essential to provide memorable interactive experiences. Our schedule included an 80-minute lab period each week, and it was my pleasure to fill that time with highly motivating hands-on activities. Frequently, when students from previous years came to visit, the conversation would turn to experiences they remembered from those activities. Often these students had gone on to careers related to biology.

I have been retired for a year now. The school administrators have done away with the weekly lab because of schedule changes. I am devastated that after all those years, they never understood the tremendous importance of all those hands-on lab experiences. They really need to see a dancing cockroach leg hooked up to an iPhone!

Pam Nester
Kutztown, Pa.

ERRATUM

In "The Right Way to Get It Wrong," by David Kaiser and Angela N. H. Creager, *Phycomyces* is described as an alga. It is a fungus.

LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/oct2012

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Solve the Nobel Prize Dilemma

Now that teams, not individuals, drive high-impact science, the Nobel Foundation should change how it awards its prize

Two teams of scientists simultaneously announce the discovery of a lifetime—a breakthrough that profoundly alters our view of the universe. A Nobel Prize is surely not far away. Yet the statutes of the Nobel Foundation state that the honor may not be "divided into more than three prizes at most." A committee in Sweden now faces a knotty choice: Who among the teams' many worthy scientists deserves to win the world's most prestigious medal?

This scenario could easily apply to the search for the Higgs boson, which appears to have reached its climax [see "The Higgs at Last?" by Guido Tonelli, Sau Lan Wu and Michael Riordan, on page 58]. But it could also describe last year's Nobel Prize in Physics, for which three researchers representing two teams totaling 51 scientists were recognized for uncovering the accelerating expansion of the universe. These three winners were deserving. Yet they did not work alone. Many other researchers made equally important contributions but will not have the special asterisk reserved for Nobel laureates next to their name.

Snubs are not new to the Nobel, of course. Physicists Nicola Cabibbo, Makoto Kobayashi and Toshihide Maskawa helped to predict a new family of quarks; today scientists use the "CKM matrix" to do calculations. Yet half the 2008 physics prize was split only between Kobayashi and Maskawa. That year's chemistry prize recognized three researchers for green fluorescent protein (GFP), now widely used as a cellular tagging tool. Not included was Douglas Prasher, the man who first cloned the GFP gene. After publishing his work in 1992, Prasher freely shared his insight with two of the eventual winners before his grant ran out. At the time of the award, he was driving a courtesy shuttle for an auto dealer.

The Nobel committees force a category error: they insist on awarding the prize to a few individuals, while in reality, the nature of the scientific enterprise has changed. Teams now perform the bulk of the highest-impact work. Whereas a century ago a patent clerk famously divined the theory of relativity in his spare time, discovering a Higgs boson requires decades of planning and the efforts of 6,000 researchers. No one person—no troika, even—can legitimately claim all the credit. The scientific papers that document the Higgs discovery are signed "The Atlas Collaboration" or "The CMS Collaboration," with members listed alphabetically in appendixes that run more than 15 single-spaced pages.

As we see it, the Nobel Foundation has two ways forward. The first is to keep the three-honoree maximum in place, but to award organizations as well as individuals. The Nobel Peace Prize has long favored this approach. The committees that choose the science prizes have never recognized an organization, but nothing in the statutes of the Nobel Foundation prohibits it. Certainly an award split between the ATLAS and CMS collaborations would make a worthy first.

Alternatively—or perhaps in addition—the Nobel Foundation should amend its statutes to allow the award to go to more than three individuals. This adjustment could help solve the dilemma surrounding the award for the theoretical work that led to the Higgs. Six researchers developed the Higgs mechanism in 1964; five are still alive today and thus eligible for Nobel's honor.

In many ways, the Nobel Prize is a charming anachronism. Recipients fly to Stockholm and meet with the Swedish royal family in white-tie tuxedos. Other scientific prizes now offer larger cash prizes. Yet the Nobel continues to capture the world's imagination—and that of the scientific community—with a 111-year pedigree of offering exemplars of extraordinary lives spent in pursuit of truth and discovery. In the years since the prize was first awarded, the nature of that pursuit has profoundly changed. It is time that the Nobel did as well. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/oct2012

PHOTOILLUSTRATION BY SCIENTIFIC AMERICAN; GETTY IMAGES *(medal)*

Kathleen A. Ryan is associate professor in the University of Florida's department of pediatrics and a member of the Emerging Pathogens Institute.

Target the Super-Spreaders

Inoculating kids is the best way to protect everyone from flu. Why don't we do it?

Influenza has been called "the last great plague of humankind" because it still poses a serious health threat to our nation and the world. If a naturally occurring variant of a bird flu virus acquired the ability to replicate in the trachea and nose of humans, it would cause a pandemic, with consequences as potentially devastating as the 1918 flu, which killed 50 million people. Because influenza viruses are found in birds and many mammalian species, it will not be possible, as it was for smallpox, to wipe influenza from the face of the earth. The only way to control it is through adequate immunization programs.

In the past, public health officials have focused on immunizing the elderly, who are at greatest risk for severe illness and death from influenza. Yet the most effective way to protect the elderly, and everyone else, is to target kids. Computer-modeling studies suggest that immunizing 20 percent of children in a community is more effective at protecting those older than 65 than immunizing 90 percent of the elderly. Another study suggests that immunizing 70 percent of schoolchildren may protect an entire community (including the elderly) from flu. Schools are virus exchange systems, and children are "super-spreaders"—they "shed" more of the virus for longer periods than adults.

Perhaps the best example of the effectiveness of childhood vaccination comes from Japan. The 1957 flu pandemic prompted the Japanese to start a school-located childhood vaccination program. For at least 10 years vaccination against influenza was mandatory for all children. Excess deaths from influenza and pneumonia, a common complication, fell by half. (Death from all causes dropped, suggesting that the illness is underdiagnosed.) The study showed that for every 420 schoolchildren immunized, one life was saved, predominantly among the elderly. Once the program ended, immunization rates fell, and death rates rose dramatically over the next few years.

Mandating flu immunization for children in schools is a nonstarter in the U.S. Still, it is possible to achieve high immunization rates through voluntary community programs centered on schools. In Alachua County, Florida, the home of the University of Florida, a school-located influenza vaccination program has been in full operation since 2009. Implemented as a coalition of schools, health departments and community advocates and with the expert advice of my colleagues Parker A. Small, Jr., and J. Glenn Morris, Jr., of the University of Florida, the program administers FluMist nasal spray, a live attenuated vaccine, free of charge to students, from pre-K to 12th grade, in public and private schools regardless of insurance status. Immunization rates of elementary students have reached 65 percent—enough to reduce the incidence of influenza in Alachua County during the past two flu seasons to nearly zero.

Such a program administered in schools across the country would raise the overall immunization level, protect our communities, and provide a basis for rapidly immunizing the U.S. population against the next pandemic strain or even against a bioterrorist attack. It would save lives and money. Seasonal flu kills 36,000 people every year in the U.S. and costs more than $10 billion. The average family of four loses about $100 in wages.

School-wide vaccinations would require a big conceptual change in immunization strategies, involving schools, communities, pediatricians and health departments. Who will fund and lead such an effort? Probably not the states, which are cutting back on public health. The federal government is grappling with rising health care costs. The health insurance industry, which stands to save billions each year in reimbursements, is the logical choice, but so far it has been unwilling to take the lead. Someone will have to. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/oct2012

Illustration by Viktor Koen

MEDICINE

The Exposure Cure

LEVI BROWN *Trunk Archive*

A major study moves food-allergy treatments a step closer to reality

As many as eight out of every 100 children in the U.S. suffer from food allergies, a rate that rose 18 percent between 1997 and 2007. Although some outgrow these reactions, many are plagued for life with symptoms that range from a tingling, itchy mouth to tightening airways and a potentially fatal drop in blood pressure.

Until now, the only way to prevent allergic reactions has been to avoid the offending foods, which can be difficult because traces of nuts, wheat and dairy lurk in many products. But a new study offers some of the best evidence that doing just the opposite—exposing patients to higher and higher doses of a food allergen—may help some overcome their sensitivity. In the largest placebo-controlled trial of its kind, Wesley Burks, a professor of pediatrics at the University of North Carolina at Chapel Hill School of Medicine, and his colleagues started 40 children with egg allergies on a dose of egg white powder equivalent to one ten-thousandth of an egg. The researchers, who published their findings in July in the *New England Journal of Medicine,* ramped up the dose, and after 22 months of therapy followed by a two-month break, 28 percent of the children were able to eat the equivalent of two and a half eggs. One year later 100 percent of those children were eating eggs and reporting no reactions. The approach, called oral immunotherapy, follows the same principle as shots for airborne allergens, although shots may be less safe for food allergies.

Researchers believe the treatment, which has also been tested for peanut and milk allergies, "teaches" the body to tolerate what it once rejected. Blood tests in children who responded to the trial showed decreased levels of the antibody IgE, which triggers the immune response, and increased levels of IgG4 antibodies, which discourage inflammation. Those who failed the egg tests may need a longer therapy period, Burks says, or they may be too sensitive to respond to therapy.

A synthetic antibody might help those extrasensitive patients by binding (thus eliminating) free IgE in the blood. It is already approved for airborne allergies and is currently in trials for oral immunotherapy. Burks says, "The hope is that we can come up with a treatment in the next few years." —*Marissa Fessenden*

ENGINEERING

Snap Judgment

An ultrafast camera may help detect cancer before it spreads

CAUGHT IN THE ACT: Dividing cancer cells.

Cancer cells that break away from a tumor and metastasize lead to 90 percent of all cancer deaths. Researchers have spent decades trying to develop blood tests that can effectively detect these circulating tumor cells. Finding them, however, can be like searching for a particular needle in a stack of needles. One milliliter of blood contains about five billion red blood cells and nearly 10 million white blood cells but only 10 tumor cells.

Researchers at the University of California, Los Angeles, have developed specialized technology that may be able to find these cells before they form new tumors, significantly boosting a patient's odds of survival. They describe the system in a July issue of the *Proceedings of the National Academy of Sciences USA*.

At the heart of the U.C.L.A. system is an ultrafast microscopic camera the researchers introduced in 2009 that captures images at about six million frames per second. This so-called serial time-encoded amplified microscopy (STEAM) camera creates each image using a very short laser pulse—a flash of light only a billionth of a second long. Its shutter speed is 27 picoseconds, about a million times faster than a current digital camera. (A picosecond is one trillionth of a second.)

The U.C.L.A. camera converts each laser pulse into a data stream from which a high-speed image can be assembled. To the STEAM camera, the investigators have added a microfluidic channel for the cells to flow through and a high-speed image processor that, they say, takes blur-free images. The team used this technology to identify breast cancer cells in blood samples. "We look at a cell's shape, size and texture, as well as its surface biochemistry," explains lead author Keisuke Goda, who recently moved from U.C.L.A. to the University of Tokyo. "Cancer cells tend to be larger than white or red blood cells. And we know that a cancer cell's shape is ill defined compared with red and white blood cells." Goda adds that a relatively noninvasive blood test would encourage people to get screened more frequently than they do now.

—Larry Greenemeier

ECOLOGY

Stealing for Biodiversity

Thieving rodents may have replaced extinct megafauna as seed dispersers

Thousands of years ago, massive elephantlike creatures wandered the landscape, where they gobbled up, and then defecated, fruit. In the process, they may have planted the seeds for early forests. Yet with these creatures long extinct, ecologists have been left with a puzzle: If the same trees are still with us, what—if anything—disperses their seeds to create today's woodlands?

The answer—at least for one type of tree—may lie in the criminal antics of a cunning rodent. A group of scientists working with the Smithsonian Tropical Research Institute in Panama and Wageningen University in the Netherlands, along with other institutions, reports that by repeatedly raiding each other's stashes, these creatures spread seeds over a much wider territory than scientists had previously recognized. Dispersal is a key factor in ensuring the survival of a species because spreading individuals over a broader range can mitigate the effects of pests, move organisms into new climatic ranges and increase the flow of genes between populations.

The rodent in question is the agouti—a house cat–size critter that resembles a tail-less squirrel. The researchers studied agoutis caching black palm tree seeds on Barro Colorado Island in the Panama Canal over one year. They set up video cameras at cache sites, attached a long thread with a transmitter unit to each of 589 seeds and radio-tracked them. More than half of the seeds cached were stolen by other agoutis and recached elsewhere, traveling as far as 280 meters from their original locations. Ultimately agoutis or other small mammals ate most of the seeds, but around 14 percent most likely grew into seedlings. The findings were published in the July 31 *Proceedings of the National Academy of Sciences USA*.

The work casts doubt on the hypothesis that megafauna were crucially responsible for seed dispersal thousands of years ago because rodents may have played a role even then. Co-author Ben Hirsch of Ohio State University and his colleagues also believe their findings offer some hope for trees in the face of modern mammalian extinctions. That a humble rodent can step into the role left by long-lost megafauna is a testament to nature's resilience.

—Daisy Yuhas

PHOTO RESEARCHERS, INC. (*top*); GABRIEL ROJO *Minden Pictures* (*bottom*)

EGOR GAVRILENKO *Corbis*

APPRECIATION

Sergei Petrovich Kapitza

The physicist and founder of *Scientific American*'s Russian-language edition worked tirelessly to advance the cause of science

Scientific American **lost a good friend on August 14 with the death of physicist and demographer Sergei Petrovich Kapitza, 84, the founding editor of *V Mire Nauki*, the magazine's Russian edition. Kapitza was at the helm of *V Mire Nauki* when it launched in 1983 in the Soviet Union, and he successfully popularized science in his home country and abroad. He was perhaps best known as host of the long-running science television show *Ochevidnoye-Neveroyatnoye* (*Evident but Incredible*), which was launched in 1973 and for which he was awarded the UNESCO Kalinga Prize for the Popularization of Science in 1979.**

Kapitza played an active role among *Scientific American*'s 14 international editions. "He was a gracious man and a thoughtful colleague," says *Scientific American* editor in chief Mariette DiChristina. "Last year he was our genial host when the entire *Scientific American* family met in Moscow for the first time in many years. He was warm and enthusiastic toward all of us."

After graduating from the Moscow Aviation Institute in 1949, Kapitza contributed significantly to the understanding of supersonic aerodynamics, applied electrodynamics and accelerator physics. He is also known for his work in developing the microtron, a type of particle accelerator.

Born on February 14, 1928, in Cambridge, England, Kapitza came from a strong scientific pedigree. His father, Soviet physicist Pyotr Leonidovich Kapitza, earned a Nobel Prize in 1978 for his discoveries and contributions to low-temperature physics. His mother was Anna Alekseevna Krylova, daughter of applied mathematician A. N. Krylov.

In 1949 Kapitza married Tatiana Damir, with whom he had three children.

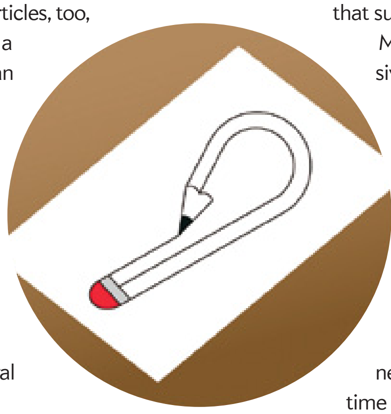
—Larry Greenemeier

PHYSICS

Stuff That Designs Itself

Self-assembling nanoparticles may be key to new materials

Like cheerleaders forming a human pyramid, particles, too, can assemble themselves into intricate patterns. In a new study, researchers at the University of Michigan found that an object's shape greatly affects how it responds to crowding and that, with a properly designed shape, tiny material building blocks known as nanoparticles could self-assemble into predictable larger structures simply by being forced to share space with neighbors. The study, which appeared in the July 27 *Science*, could help researchers design new materials.



The investigators ran computer simulations of 145 different particles having idealized polyhedral shapes. (A polyhedron is a solid formed by planar faces.) When packed closely with identically shaped particles, most of those polyhedrons assembled into a crystal lattice or a crystal-like arrangement. Study co-author Sharon Glotzer, a Michigan professor of chemical engineering, materials science and physics, and her colleagues had previously found that some particle shapes naturally self-assemble. Yet the new simulations showed that such behavior is the rule, not the exception.

Moreover, some of the shapes displayed an impressively coordinated assembly process. A pyramid shape with a square base joined into "supercubes" of six pyramids apiece, which then formed a larger cubic lattice. The researchers also found that the collective behavior of a given particle type is far from random. In fact, two numbers all but foretell the outcome. A number called the isoperimetric quotient, which roughly captures a particle's shape, and a measure called the coordination number, which describes how many neighbors a particle has, predicted 94 percent of the time which crystalline form a polyhedron would take.

The relation between shape and self-assembly could be used to tailor nanoparticles to exhibit a specific collective behavior.

"This is sort of a holy grail of materials research: to just look at a building block and be able to say, 'Oh yes, I know all the kinds of crystal structure that would be stable with this,'" Glotzer says. "This study allows us to take a first step in that direction." *—John Matson*

Illustrations by Thomas Fuchs

ADVANCES

SPACE

Primordial Pinwheel

Astronomers spot the oldest prominent spiral galaxy yet

ARTIST'S rendering of galaxy BX 442

The early universe was a rough-and-tumble place. Galaxies smashed together with much more regularity than they do today, and the insides of galaxies were chaotic, clumpy pods of stars. It was no place for an orderly, delicate swirl of a galaxy like the Milky Way or Andromeda.

By scanning hundreds of galaxies that existed just a few billion years after the big bang, however, a group of astronomers has turned up a diamond in the cosmic rough. The researchers found a rare early galaxy with pronounced spiral arms, which they reported in the July 19 *Nature*. (*Scientific American* is part of Nature Publishing Group.) And that galaxy's unique circumstances may help explain why spirals are so infrequent at that epoch. The newfound galaxy, known as BX 442, was identified in Hubble images as a spiral that existed three billion years after the big bang. It appears to fit the bill for a variety called a grand-design spiral, in which pronounced spiral arms lend a well-defined shape to the galaxy's disk of stars.

Spirals are common in the modern universe, but as astronomers gaze across the cosmos at objects farther and farther away—and hence further and further back in time—spiral structure starts to peter out. Instead of orderly swirls, astronomers see lumpy, blobby galaxies going through the cosmic equivalent of an awkward phase. But somehow a regular spiral structure was imprinted on BX 442, perhaps by a recent grazing encounter with a much smaller galaxy. "What seems to set it apart, as best as we can tell, is that it has this little companion galaxy off to the side," says lead study author David Law, an astrophysicist at the University of Toronto. If the companion galaxy were the trigger, the spiral arms would "probably fade away within about 100 million years or so," Law says. The transitory nature of a spiral structure at that epoch could explain why spirals are so rare.

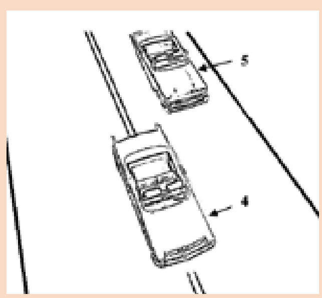
BX 442 could have also generated its own spiral structure without a nudge from its neighbor. Clumps of stars and gas within a galaxy can cause spirals to form, and BX 442 appears to contain at least one large clump along one of its spiral arms.

It may be that numerous different mechanisms can shape a spiral galaxy. Many more examples from different cosmic epochs should be accessible for study once next-generation observatories, such as NASA's James Webb Space Telescope, come online. *—John Matson*

PATENT WATCH

Wide angle substantially nondistorting mirror: Every passenger's side mirror carries a warning that objects "are closer than they appear" because the curved surface designed to give drivers a wider field of view ends up distorting distance. But U.S. regulations require the driver's side mirror to be flat because depth perception was judged to be more important than field of view at that location. The result is a blind spot just beyond the driver's left shoulder. While working on a way to give soccer-playing robots a 360-degree view, R. Andrew Hicks, a mathematician at Drexel University, figured out how a small mirror could reflect a wide view without distortion. That work inspired him to create a blind spot–free driver's side mirror.

After years of algorithm tweaking, Hicks came up with patent No. 8,180,606, which describes a driver's side mirror with a field of view of at least 45 degrees, as compared with current mirrors that reflect only 15 to 17 degrees.



Hicks's algorithm employs thousands of calculations to create a "weird wavy surface," which bounces each ray of light toward the driver in just the right way, he says. The curves are subtle, however, and the mirror appears smooth. Manufacturers only recently developed the technology to shape this kind of free-form surface. Before companies roll out vehicles with the updated mirror, regulations will need to change, but the new accessory could debut as an aftermarket add-on in the next few years. *—Marissa Fessenden*

COURTESY OF JOE BERGERON *Dunlap Institute for Astronomy & Astrophysics* (top); COURTESY OF U.S. PATENT AND TRADEMARK OFFICE (bottom)

COMMENT AT ScientificAmerican.com/oct2012

TECHNOLOGY

Seeing in the Rain

Novel headlights illuminate the road, even in bad weather

Drive through pounding rain or a snowstorm at night, and you will notice that your headlights illuminate the drops or flakes more than they shed light on the road ahead. New "smart" headlights may reduce this hazard by shining light into the spaces between the precipitation.

The headlight is actually an array of bulbs, and the key to its success is that even a sheet of heavy rain is mostly empty space. The system was designed by Carnegie Mellon University's Srinivasa Narasimhan and his colleagues at institutions including Texas Instruments and France's MINES ParisTech. It uses a digital camera to track the motion of individual raindrops or snowflakes and applies a computer algorithm to predict where each bit of precipitation will be a few milliseconds later. It then deactivates bulbs that would otherwise illuminate the drops or flakes in their predicted positions.

The camera captures an image every eight milliseconds and adjusts the bulbs in the headlamp within 13 milliseconds. Narasimhan claims it reduces the visibility of rain four meters away by about 70 percent when a car is moving at 30 kilometers per hour, and he plans to test the system in cars traveling at least 95 kilometers per hour. The researchers are developing quicker ways of transferring information from the camera to the headlight, but it will likely be another two or three years before his smart system is ready for the road. *—Larry Greenemeier*

GREAT CATCH: A fourth-century Roman mosaic with groupers.

BIOLOGY

The Art of Fishing

Ancient mosaics help scientists track grouper populations

A few years ago Paolo Guidetti was leafing through a book on ancient art when he came across a Roman mosaic showing a man's legs dangling from the mouth of an enormous fish. Struck by the picture, Guidetti, a biologist at the University of Salento in Italy, recognized the fish as one that he studies: the dusky grouper.

Today fishers would be hard-pressed to find a dusky grouper that large and so close to the sea's surface. The fish, found throughout the Mediterranean, are endangered. While they can grow to a length of more than four feet and a weight of 100 pounds, most are much smaller, and at sites where fishing pressures are highest they occupy waters too deep to leap out and eat anyone.

To help groupers recover, fisheries managers have established marine reserves throughout the Mediterranean. Evidence suggests the reserves are working: groupers are becoming more common at a variety of depths, and they are generally larger. Yet Guidetti and Fiorenza Micheli, a biologist at Stanford University, wanted to have a more accurate sense of the grouper's historical abundance. To determine just how far recovery efforts had to go, it would be better to know how the fish had fared thousands of years ago.

But how to do that? Thousand-year-old data are hard to come by, so Guidetti and Micheli turned to the mosaics that had first caught Guidetti's eye. They looked in museums and books. They spread the word among other biologists. It took a couple of years, but they were able to cobble together 73 Etruscan, Greek and Roman mosaics from between the first and fifth centuries that showed fish or fishing scenes. Of those, 23 had groupers.

"Using the mosaics, we were able to assess how big groupers used to be and how they were caught," Micheli says. What they saw surprised them. In some mosaics, fishers used nets and harpoons to catch groupers at the water's surface—techniques that would never work today. Others showed groupers so large that they more than justified their historical reputation as sea monsters. "It suggested that groupers were considerably more common and accessible than anyone had thought," says Micheli, whose findings were published late last year in *Frontiers in Ecology and the Environment.*

Artistic license and a fisher's penchant for exaggeration aside, Guidetti and Micheli argue that older, extrascientific sources can aid in calibrating conservation and management aims. "For these types of questions, we must be willing to consider the importance of less quantitative, more anecdotal evidence," Micheli says. "We wanted to emphasize art as a form of information." *—Eric Wagner*

PSYCHOLOGY

Bird Brains

Until the age of eight, kids are little better than jays at solving a common puzzle

In an Aesop fable, a thirsty crow wanting to drink from a pitcher must first raise the water level, so he drops pebbles in the container. In real life, the Eurasian jay can perform the same task. But just how smart is it?

Researchers challenged jays and human children with puzzles like the one in the fable. And until the kids reached the age of eight, their results were similar to the birds'. The study appeared in July in *PLoS ONE.*

In one test, a prize was put in a tube of either water or sawdust. About half the birds needed multiple trials to learn that dropping stones into the liquid, but not the dust, lifted the reward up to within reach.

When children between four and seven were faced with the same test, they learned in a similar fashion, taking about five trials to realize that the token in the water tube could be retrieved—although they did pick up the task faster than the birds. Older children learned more quickly, and those aged eight or older solved it the first time they tried. ***—Sophie Bushwick***

GIANNI DAGLI ORTI *Art Archive at Art Resource*

WHAT IS IT?

Underwater ghost: Russian marine biologist and deep-sea photographer Alexander Semenov captured this image of *Caprella septentrionalis,* also known as the "ghost" or "skeleton" shrimp. The species, which can grow up to 3.2 centimeters long, spends most of its time attached to sea grasses, filter feeding on the microscopic scraps that float by. But when it has to get somewhere, it moves with a measured, high-arching gait similar to that of an inchworm. *—Becky Crew*

STAT

$70,000

Amount the U.S. spends on cancer care per case

$44,000: Average amount that 10 European countries, including Sweden, Germany and France, spend on cancer care per case

11.1: Average survival, in years, of an American patient diagnosed with cancer

9.3: Average survival, in years, of a patient diagnosed with cancer in one of the same 10 European countries

PHYSICS

A "Just Right" Guitar

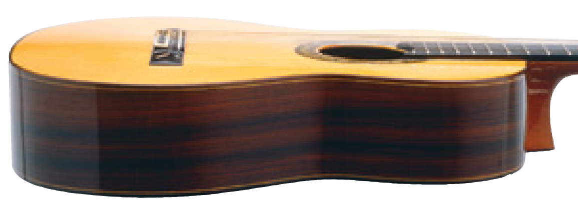
A 68-millimeter-thick instrument produces the best-quality sound

Kazutaka Itako, an electrical engineer at the Kanagawa Institute of Technology in Japan, has played the guitar since he was six years old. Satoshi Itako, who has a master's degree in electrical engineering, works as a guitar fabricator. Together the brothers have been investigating the optimal shape for guitars.

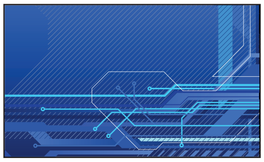
Experts have settled many questions relating to the best shape for violins, but far less research has been done on guitars. The Itakos' preliminary work, presented in May at the Acoustics 2012 conference in Hong Kong, looks at one variable: guitar depth. They crafted four nearly identical instruments, ranging from 58 to 98 millimeters deep.

The Itako brothers tested the tonal quality and harmonics of four guitars, while a performer played open strings with two different strumming styles, using both objective and subjective measures. With an oscilloscope, they measured the harmonics, integral multiples of a fundamental tone. (A pure wave has only one frequency, yet it sounds sterile and artificial. The more harmonics, the richer the sound quality.) In addition, nine musically trained listeners evaluated the guitars.

The 68-mm-thick guitar included the richest combination of harmonics, and six of the nine listeners rated it as having the best tone quality. The Itakos are now moving on to the question of how the size of the sound hole alters the guitar's tone. After that, they plan to determine whether a synthetic material, such as fiberglass, could make instruments that are just as sonorous as wood versions, which are time-consuming and finicky to make. The Itakos' goal is to identify ideal dimensions and materials for a high-quality subprofessional instrument, which would allow more amateur strummers to buy good guitars at affordable prices. *—Evelyn Lamb*



COURTESY OF ALEXANDER SEMENOV *(left)*; GETTY IMAGES *(right)*



NANOSCIENCE
Chris Sorensen, Ph.D.

Fire, Fractals and the Divine Proportion
Physicist Chris Sorenson discusses the mysteries, beauties, and curiosities of soot. Take an unlikely journey of discovery of soot to find fractal structures with non-Euclidian dimensionality, networks that tenuously span space and commonalities among spirals, sunflowers and soot. Gain an appreciation for the unity of Nature, and the profound lessons in the commonplace as well as the sublime through soot!

Light Scattering
Take a *particle* physics perspective and ask: how do particles scatter light and why does light scatter in the first place? What are the effects of scattering on the polarization? How do rainbows, glories and sundogs work? How do light scattering and absorption effect the environment? Get the latest on scattering and see your universe in a new light.

Nanoparticles: The Technology.
Nanoscience has spawned a significant nanotechnology. Explore new nanomaterials such as self cleaning surfaces and fibers stronger yet lighter than steel. Then we'll do some informed daydreaming about far reaching possibilities like nanobots that could take a "fantastic voyage" inside your body or stealth materials for the invisible man. Enjoy reality science fiction at its best!

Nanoparticles: The Science.
What makes "nano" so special? Why does nano hold such great promise? Take a look at the clever chemistry that creates the nanoparticle building blocks of the new nanomaterials. Find out why physical properties of nanoparticles differ from larger particles. When this session is over, you'll understand why small can be better.

ASTROBIOLOGY
Speaker: Seth Shostak, Ph.D.

Hunting for Life Beyond Earth
Is Earth the only planet to sport life? Researchers are hot on the trail of biology beyond Earth, and there's good reason to think that we might find it within a decade or two. How will we find alien biology, and what would it mean to learn that life is not a miracle, but as common as cheap motels?

Finding E.T.
Life might be commonplace, but what about intelligent life? What's being done to find our cosmic confreres, and what are the chances we'll discover them soon? While most people expect that the cosmos is populated with anthropomorphic aliens aka "little gray guys with large eyes and no hair" you'll hear that the truth could be enormously different.

What Happens If We Find the Aliens?
One-third of the public believes that aliens are visiting Earth, pirouetting across the skies in their saucers. Few scientists agree, but researchers may soon discover intelligent beings sharing our part of the galaxy. Could we handle the news? What facts could be gleaned

immediately, and what would be the long-term effects such a discovery would have on us and our institutions, such as religion?

The Entire History of the Universe
Where and when did the cosmos begin, and what's our deep, deep future? The book of Genesis gives only a short description of the birth of the cosmos, but modern science can tell a more complex tale. How did the universe get started, and could there be other universes? And how does it all end, or does it end at all?

SKEPTICISM
Speaker: Michael Shermer, Ph.D.

The Believing Brain: From Ghosts and Gods to Politics and Conspiracies — How We Construct Beliefs and Reinforce Them as Truths
The brain as a "belief engine"? Learn how our brains' pattern-recognition and confirmation bias help form and reinforce beliefs. Dr. Shermer provides real-world examples of the process from politics, economics, and religion to conspiracy theories, the supernatural, and the paranormal. This discussion will leave you confident that science is the best tool to determine whether beliefs match reality.

Skepticism 101: How to Think Like a Scientist
Harvest decades of insights for skeptical thinking and brush up on critical analysis skills in a lively session that addresses the most mysterious, controversial, and contentious issues in science and skepticism. Learn how to think scientifically and skeptically. You'll see how to be open-minded enough to accept new ideas without being *too* open-minded.

The Science of Good and Evil: The Origins of Morality and How to be Good Without God
Tackle two challenging questions of our age with Michael Shermer: (1) The origins of morality and (2) the foundations of ethics. Dr. Shermer peels back the inner layers covering our core being to reveal complex human motives — good and evil. Gain an understanding of the evolutionary and cultural underpinnings of morality and ethics and how these motives came into being.

The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics
How did we evolve from ancient hunter-gatherers to modern consumer-traders? Why are people so irrational when it comes to money and business? Michael Shermer argues that evolution provides an answer to both of these questions through the new science of evolutionary economics. Learn how evolution and economics are both examples of complex adaptive systems. Get your evolutionary economics tools together.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

IGUAZU FALLS

March 5–7, 2013 — Surround yourself with 260 degrees of 240 foot-high walls of water at Iguazu Falls. Straddling the Argentinian-Brazilian border, Iguazu Falls is split into about 270 discrete falls and at peak flow has a surface area of 1.3 million square feet. (By comparison, Niagara Falls has a surface area of under 600,000 square feet.) Iguazu is famous for its panoramic views and breath-taking vistas of huge sprays of water, lush rainforest, and diverse wildlife.

You'll walk Iguazu National Park's extensive and well-engineered circuit paths over the Falls, go on a boat ride under the Falls, be bowled over by the massiveness and eco-beauty, and take a bazillion pictures.

MACHU PICCHU

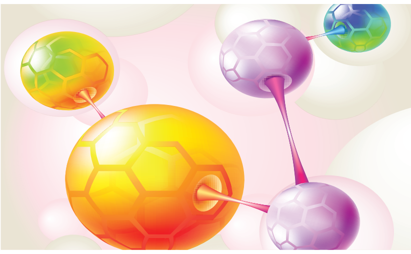
February 15–20, 2013 — Scale the Andes and absorb Machu Picchu's aura. Visit this legendary site of the Inca World, draped over the Eastern slopes of the Peruvian, wrapped in mystery. Whether it was an estate for the Inca emperor Pachacuti or a site for astronomical calculations, it captures the imagination. Visit Machu Picchu, and see for yourself the massive polished dry-stone structures, the Intihuatana ("Hitching Post of the Sun"), the Temple of the Sun, and the Room of the Three Windows. Iconic ruins, rich flora and fauna, and incomparable views await your eye (and your lens).

EASTER ISLAND

Febrruary 16–20, 2013 — The moai of Easter Island linger in many a mind's eye, monumental statues gazing inland, away from the South Pacific. Join Bright Horizons on a four-day pre-cruise excursion to explore the mysteries of Rapa Nui. Visit archaeological sites, learn about the complex cultural and natural history of the island, and absorb the ambiance of one of the most remote communities on Earth. Come along on an adventure where archaeology and environment create memories and food for thought.

GALAPAGOS

February 12–20, 2013 — Enter an unearthly natural world in an eight-day pre-cruise excursion to the Galapagos Islands. "See the world in a grain of sand" and hone your knowledge of evolution with your observations in the Galapagos, a self-contained natural history laboratory. We'll tour Santiago, Chile, and straddle the Equator at the "Middle of the World" complex in Quito, Ecuador. Then off to the Galapagos for a four-day expedition on the mv Galapagos Legend. Accompanied by certified naturalists see the incredibly diverse flora and fauna up close. You'll have the opportunity to swim and snorkel, and photograph legendary wildlife and wild landscapes. Join Bright Horizons in the Galapagos for all the intangibles that communing with nature provides.



Chemistry

Speaker: Robert Hazen, Ph.D.

Genesis: The Scientific Quest for Life's Origins — Is life's origin an inevitable process throughout the cosmos, or is it an improbable accident, restricted to a few planets (or only one)? How does a lifeless geochemical world of oceans, atmosphere and rocks transform into a living planet? Find out how scientists use experimental and theoretical frameworks to deduce the origin of life.

The Diamond Makers
Diamond forms deep in Earth when carbon experiences searing heat and crushing pressure. Decades ago General Electric scientists learned how to mimic those extreme conditions of Earth's interior in the laboratory to make synthetic diamonds. Learn the human drama and technological advances involved in producing this coveted gem and industrial tool from carbon-rich substances.

The Story of Earth: How the Geosphere and Biosphere Co-evolved
Earth is a planet of frequent, extravagant change. Its near-surface environment has transformed over and over again across 4.5 billion years of history. Learn about the work of Dr. Hazen and colleagues that suggests that Earth's living and nonliving spheres have co-evolved over the past four billion years.

Chemical Bonding — The solid, liquid, and gaseous materials around us depend on the specific elements involved and the chemical bonds that hold those atoms together. By looking at the nature and significance of ionic, metallic and covalent bonds you'll gain a new understanding of the workings of the world around you.

Quantum Physics

Speaker: Benjamin Schumacher, Ph.D.

Private Lives of Quantum Particles
Quantum systems can exhibit all sorts of bizarre behavior. But many of these phenomena can only be observed under conditions of the strictest privacy, where systems are "informationally isolated" from the world. These are not accidental features of quantum theory. They are inescapable facts about the microscopic world: Quantum physics is what happens when nobody is looking.

2π Is Not Zero (But 4π Is) — If you rotate any geometrical shape by 360 degrees (2π radians) about any axis, you will end up with exactly the same shape. But this fact, seemingly obvious, is not true for quantum particles with spin. Learn how a rotation by 2π makes a big difference, and how it all comes down to a simple minus sign — probably the most important minus sign in all of physics. Enjoy quantum fun, demystified by Dr. Schumacher.

The Physics of Impossible Things
Physicists find it surprising useful to ponder the impossible. Using the laws of nature, assess the possibility of science fiction's favorite phenomena and explore seemingly impossible things, which while odd, are possible. Venture into the study of impossible things and come away with an affirmation of the consistent logic of nature, and renewed wonder at real phenomena.

The Force That Isn't a Force — What makes a rubber band elastic? Its entropy, the microscopic disorder of its molecules. Now, entropy may provide a clue to the most familiar and mysterious of the basic forces of nature: gravity. Explore the link between entropy and gravity, and gain fascinating and unexpected insights of contemporary theoretical physics.

Archaeology

Speaker: Kenneth Harl, Ph.D.

From Old Europe to Roman Provinces
Explore the prehistoric foundations of Scandinavia and the Viking Age from ca. 3000 B.C. to 400 A.D. From Megalithic cultures to the arrival of Indo-Europeans, to Northern Bronze Age innovations and Celtic and Roman contributions, learn the unique environmental, cultural, and social factors that create a context for the Vikings.

Great Halls and Market Towns in Viking Age Scandinavia — Using archaeological and literary sources (especially saga and Eddas), learn how the "great halls" emerged as the main focus of Scandinavia civilization. Find out how the development of towns facilitated trade and were vital for the transformation and technological advance of Scandinavian society.

Ships and Ship Building in the Viking Age — European history records the effectiveness of the fearsome Viking longship; find out the features and technologies that made it so. Based on archaeological finds, learn about the multi-millennial evolution of the longship, from linden to oak, dugout to mast and sail. Gain an appreciation for the form and function, as well as the wider implications of Norse naval mastery for three hundred years.

Warfare in the Viking Age — The Viking's applied technologies led to three centuries of robust military and economic power for Scandinavia. Discover what factors made the Vikings accomplished warriors and learn what archaeological finds tell us about Viking exploration, settlement, and development of kingdoms.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

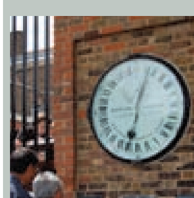
NORWEGIAN FJORDS
JULY 5–15, 2013

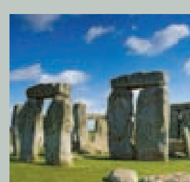
The Royal Observatory and the Churchill War Room/Museum (July 4)

Take the road less traveled in London, visiting two less well known gems of the City, both uniquely fascinating and inspiring.

Courage, duty, shared sacrifice, and conviction are the foundation of the Churchill Cabinet War Rooms. Hidden in plain sight in the heart of London, a scant 600 miles from Berlin. Step back in time and discover how Churchill and Britain's government functioned in secrecy in these quarters, from the Blitz to VE Day. The furnishings, maps, and ephemera are as they were on VE day, May 8, 1945. Hear the stories and imagine life under bombardment in the simple and inspiring environment of the Cabinet War Rooms.

Are you the precise type? Are you a fan of Google maps or GPS? Or Cutty Sark? Join us on a tour of maritime Greenwich, where our prime objective is visiting the Royal Observatory, Greenwich, home of the Prime Meridian of the World and Greenwich Mean Time. Stroll a deeply historic corner of London significant in local, national, and international culture. See the Royal Observatory, the National Maritime Museum, the tea clipper Cutty Sark, and the Royal Naval College. Master the lingo of time — UT0, UT1, UTC, and GMT. Stand astride two hemispheres on the Prime Meridian, a moment sure to be recorded on your timeline.





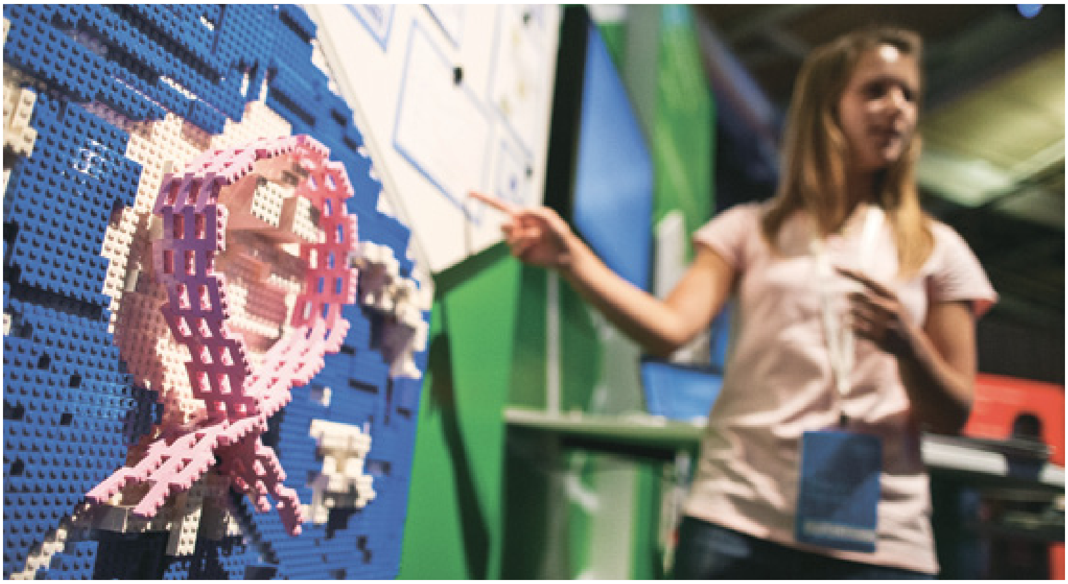
Stonehenge and Bath (July 3)

Pass a day on the Salisbury Plains and Somerset Hills, absorbing the history of two spots with ancient cultural roots.

Mute, mysterious, and megalithic, Stonehenge calls to us across the millennia. We'll respond, and walk the site in its details. Learn the significant geography, the archaeological and astronomical background, and the key stone names. But those are just the facts — the memories and true meaning of Stonehenge will be up to you.

Bath beckons the seasoned traveler. People are drawn to Bath to see its honey-colored Bath limestone buildings, and to explore its 2,000 year history as a place of relaxation and restoration. Plumb the details and nuances of Bath's fusion of architecture, culture, and history in a city with many echoes of and homages to the ancient world, while embodying the Georgian worldview.

For more info please call 650-787-5665 or log on to ScientificAmerican.com/Travel



PROFILE

NAME
Brittany Wenger

TITLE
High school senior

LOCATION
Lakewood Ranch, Fla.

WINNING: Wenger demonstrates her project at July's Google Science Fair in Mountain View, Calif.

SCIENTIST IN THE FIELD

Coding Her Way to the Top

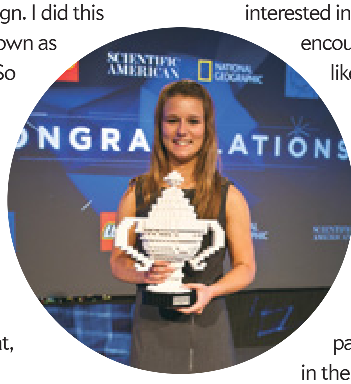
This year's Google Science Fair winner talks about how she's helping doctors detect breast cancer less invasively and why more girls don't go into computer science

How did you feel when you heard you had won not only your age category but also the grand prize at the July 23 awards ceremony?
I was just so excited. It was a surreal experience walking up there. I don't even know how I got up there.

Tell me about your project.
I taught the computer how to diagnose breast cancer so it could determine whether a breast mass is malignant or benign. I did this because currently the least invasive form of biopsy, known as a fine-needle aspirate, is actually the least conclusive. So a lot of doctors can't use it.

I created an artificial neural network, which is a type of program that learns based on its experiences and mistakes, so it classifies problems that are far too complex for humans to classify. Then I fed information into the neural network from a database of fine-needle aspirates.

Currently the network is 99.1 percent sensitive to malignancies, and I ran 7.6 million trials and proved that, as I get more data, the success rate increases and the inconclusivity rate decreases, so I think with more data it will prove to be hospital ready.



What inspired your project?
In the seventh grade I grew fascinated by artificial intelligence, which I came across while working on a school project. I went home that night, and I bought a computer programming book and, with no experience, decided that was what I was going to do with the rest of my life.

Computer science is one area where men still outnumber women. Why do you think that's the case?
I think sometimes there's a stereotype around computer science, that it's just video game development, and more boys are hard-core game developers than girls. But you have to realize it's our Web sites, our Google tools, it's our Facebook, and I think that you could reach girls more if you could appeal to what they're using computer science for.

But also I think we've come a long way. More girls are getting interested in science, and I know it used to be that girls weren't encouraged, but I've never felt like I couldn't go into science, like I was being discriminated against because I was a girl.

Have you decided what career path you'd like to pursue?
I want to be on the frontier of cancer research, finding the cures that are going to save lives and doing things with computer science that can be the technologies of the future. I also want to be a pediatric oncologist, so I hope to intertwine my passions for research, computer science and patient care in the future.

What are the next steps for your project?
It will take a long time, but I hope to scale it up and bring it into hospitals. I put my neural network into the cloud because the cloud is this amazing, elastic entity that allows for a million hospitals to access it tomorrow if they want and to provide feedback. I'm so happy to have won the Google Science Fair because it will give me a new platform, and people will take me more seriously. *—Anna Kuchment*

ANDREW FEDERMAN

COMMENT AT ScientificAmerican.com/oct2012

Best of the Blogs

ECOLOGY

Underground Network

Plants have microbiomes, too

BACTERIA ***(in green)*** **on the surface of an** ***Arabidopsis*** **root.**

To human eyes, the soil may look like a brown layer of plant mush that fits into the rocks, but it is actually a highly complex living environment. Not only must the bacteria that live within it share their space with small animals, protozoa and fungi, but they also must work around giant complexes of tree roots. These roots are not just static objects but take an active part in shaping the microbial communities around them.

As an ex-biochemist, I am used to the idea of studying plant-microbe interactions by exploring only one plant and one microbe, so I was fascinated by recent research at the University of North Carolina at Chapel Hill and other institutions that looked at entire microbial ecosystems. Researchers collected two types of soil from different locations and grew samples of the plant *Arabidopsis thaliana* in each one. They then collected soil that had grown around the roots and looked at the bacterial species within that soil, as well as the bacterial species growing within the roots themselves. Collaboration with a next-generation sequencing team allowed them to identify the various bacterial species present. They found that a subset of all the bacteria in each soil was found clustered around the roots, and an even smaller subset was allowed inside. Examining the bacteria inside each plant revealed a core microbiome common to all the plants as well as a separate set of bacteria that plants recruited depending on soil type.

Because bacteria help to provide nourishment for plants, such information might help investigators find ways to tweak plant-bacteria interactions in ways that enable vegetation to grow and possibly even thrive in nutrient-poor soils. *—S. E. Gould*

Adapted from the Lab Rat blog at blogs.ScientificAmerican.com/lab-rat

PHYSICS

Urge to Merge

Upgraded detectors may soon "see" colliding black holes

In his 1994 book *Black Holes and Time Warps,* physicist Kip Thorne wrote of the tantalizing discoveries to come in the 21st century. In particular, the existence of gravitational waves—ripples in the fabric of space and time—might soon graduate from theoretical prediction to known fact. And those waves could carry all-important hints about their origins in the motion or collision of extremely massive objects.

"Gravitational-wave detectors will soon bring us observational maps of black holes, and the symphonic sounds of black holes colliding—symphonies filled with rich, new information about how warped spacetime behaves when wildly vibrating," Thorne wrote.

That time is nearly upon us, he now believes. The California Institute of Technology theorist writes in the August 3 issue of *Science* that in five years' time, ongoing upgrades to the world's leading gravitational-wave observatories will make those instruments sensitive enough to detect the waves, which would provide yet another confirmation of Einstein's general theory of relativity. The detection would also open up a new regime for studying black holes, those cosmic gluttons whose gravitational pull is so strong that it forms a one-way funnel into their maw.

As of now, astrophysicists can only infer the presence of a black hole by monitoring the environs around the putative object. In the case of Sagittarius A*, in the center of our own Milky Way galaxy, for instance, astronomers can see flares of radiation emanating from the black hole's location, caused by infalling material heating up and radiating outside the event horizon. Stars at the galactic center betray the presence of Sagittarius A* as well—their orbits point to the existence of a nearby compact object with the mass of four million suns.

The strong gravitational-wave signature expected from merging black holes would carry a wealth of information both about the objects involved and about their cataclysmic interaction.

Two major gravitational-wave detector projects have been on the lookout for these spacetime ripples, but so far the search has not produced any results. Both the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo observatory are L-shaped instruments with extremely long arms—four kilometers for the two LIGO facilities in Washington and Louisiana and three kilometers for Italy's Virgo. They rely on long-baseline interferometry, firing lasers down the perpendicular arms to see if one direction has been stretched or compressed relative to the other by a passing gravitational wave. "The advanced LIGO and advanced Virgo interferometers are now being installed and by 2017 should reach sensitivities at which black-hole mergers are observed," Thorne writes. Sounds like the race is on to detect gravitational waves, one of the biggest prizes in physics. *—John Matson*

Adapted from the Observations blog at blogs.ScientificAmerican.com/observations

COURTESY OF SARAH LEBEIS

Deborah Franklin is based in San Francisco and has reported on science and medicine for NPR, the *New York Times, Fortune* and *Health Magazine.*

Drug Detectives

Physicians struggle to curb the growing number of lethal overdoses

BARTHOLOMEW COOKE *Trunk Archive*

The two young men who showed up retching and wild-eyed in an emergency room in Portland, Ore., last summer insisted they had swallowed nothing but an ordinary soft drink before one collapsed. Yet their odd coloring suggested otherwise. Fifteen minutes after they had downed the drink, their lips and skin turned a startling blue. Their blood was as dark as chocolate.

Eventually one of the men confessed: they had spiked their soda with a bitter liquid they bought online. They meant to order "2C-E," a man-made hallucinogen that they heard was similar to Ecstasy or LSD. What they received instead from a chemical company in China was aniline, an industrial solvent that ruptured their red blood cells, starved their tissues for oxygen and nearly killed them. Whether the substitution was their mistake or the company's, no one knew. "For quite a while after they got to the ER," says Zane Horowitz, medical director of the Oregon Poison Center, "we didn't know what exactly they had taken, and neither did they."

Horowitz and other toxicologists say the range of legal and illegal drugs now available to anyone with a credit card or well-stocked family medicine chest is broader and, in some ways, more dangerous than ever before. Bored teens seeking the latest high are only part of the problem. Patients who double down on long-acting prescription narcotics or mix some medicines with one another or with alcohol are vulnerable, too. The escalating death toll from drug use in the U.S. is startling, as a recent overview from the Centers for Disease Control and Prevention has confirmed. Accidental poisoning has now replaced car crashes as the nation's leading cause of fatal injury, and 89 percent of those poisonings result from drugs.

The magnitude of the problem has legislators, doctors and public health experts searching for solutions. Last July, President Barack Obama signed into law the Synthetic Drug Abuse Prevention Act of 2012, nationally outlawing the manufacture, sale and possession of 2C-E and 25 other "designer" recreational drugs. To try to rein in prescription drug abuse, at least 49 states have authorized funding for electronic databases that ultimately aim to identify physicians who overprescribe narcotics, as well as addicts who "doctor shop" to load up on pain relievers or stimulants.

Meanwhile medical toxicologists have surprising advice for emergency room teams treating overdoses: rely less on standard blood and urine tests when trying to identify drugs of abuse because those lab tests can be grossly misleading. Instead, these medical sleuths say, asking sharper questions will likely save more patients.

NEW NARCOTICS

DESPITE THE RECENT INCREASE in deaths from designer drugs—recreational compounds that are chemically tweaked to stay ahead of the law—a less exotic threat accounts for the most common type of drug poisoning. In the most recent analysis of all overdose deaths in the U.S., more than 40 percent involved prescription narcotics. Sales of these strong painkillers, including oxycodone, hydrocodone and methadone, have climbed, too, jumping by 300 percent between 1998 and 2008, according to the CDC, as doctors have prioritized alleviating the severe pain of cancer, surgery and serious injury.

In the past decade research has firmly demonstrated that a short course of prescription narcotics can safely reduce suffering. But the abuse of these potentially addictive drugs, alone or in combination, is particularly deadly. A 2008 study in the *Journal of the American Medical Association* profiled the problem in West Virginia: 56 percent of 275 people who overdosed on prescription narcotics had not been prescribed the medication that killed them. Another 21 percent had received prescriptions for narcotics from five or more doctors in the year before

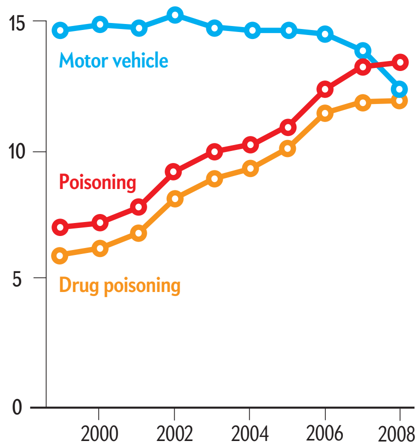
they died, a pattern that suggests they had doctor shopped to obtain more pills than any one physician would supply. National statistics underscore the risk: legal narcotics now kill more people every year than heroin and cocaine combined.

Not only are prescription narcotics more widely available than ever before, some also stay in the body longer. High-dose, extended-release pills are convenient for patients seeking uninterrupted relief from severe pain throughout the night, for example, but they also make overdose more likely if taken incorrectly. Some recreational abusers pulverize long-acting 60-milligram pills of oxycodone to snort or smoke it, thereby sending a potentially toxic quantity into the bloodstream all at once.

Well-meaning pain patients run afoul of the pills, too. “I get patients who tell me, ‘I ran out of my medicine, so my neighbor gave me some of his,’ ” Horowitz says. “But it turned out the neighbor was taking a much higher dose.”

Rising Death Toll

Deaths per 100,000 (U.S.)



POISONING is now the leading cause of death from injuries in the U.S., surpassing car crashes. Nearly nine out of 10 of those fatal poisonings are caused by medicinal or recreational drugs.

SOURCE: NATIONAL VITAL STATISTICS SYSTEM, CDC/NCHS

The greater availability of prescription drugs also makes it dangerously easy to mix medications. In the *JAMA* overdose study, nearly 80 percent of those who died were on a medley of drugs that usually included benzodiazepines (commonly prescribed for anxiety or insomnia) and had sometimes imbibed alcohol as well. That pattern of mixing often bespeaks an underlying addiction, the researchers say. In high-enough doses, each of those drugs can slow breathing, and the combination is particularly dangerous, says Jane Prosser, an emergency medicine physician at Weill Cornell Medical Center in New York City. “This is one of those cases where one plus one equals four.”

An overdose in an older patient, who is more likely to be undergoing treatment for multiple chronic conditions, can be especially tough to diagnose in the emergency room, Prosser says. “A confused elderly person comes to the ER and says, ‘I feel very weak and dizzy.’ Is that their cancer? The chemo? The pain meds? The fact that they’re dehydrated because they’ve been vomiting and have diarrhea? It can be very hard to tell.”

WHEN LAB TESTS GO WRONG

ALTHOUGH ADVANCED ANALYTICAL techniques can selectively identify any drug, they are too expensive and slow to be useful in a medical emergency, says Mark B. Mycyk, a medical toxicologist at John H. Stroger, Jr., Hospital of Cook County in Chicago. And the standard panels of quicker screening tests for drugs in blood and urine have not kept up with shifts in the types of drugs people abuse.

“Those core [toxicology] screens were developed for the war on drugs in the workplace in the mid-1970s and are designed mostly to pick up heroin, cocaine and marijuana use,” Mycyk says. The tests will not detect the increasing number of barely legal or illegal recreational drugs such as 2C-E that come in many slightly rejiggered versions because of creative chemists looking to make a buck. Even many legitimate medicines, including the antianxiety pills Ativan and Xanax and the painkillers methadone and oxycodone, do not show up on the standard hospital drug-screening tests. Relying on lab results, Prosser says, can, in this case, foil diagnosis and misguide treatment.

Say a man addicted to methadone comes into the emergency room unconscious after also taking a hefty dose of Xanax. The doctor, trying to figure out why the patient is unconscious, screens his urine for sedating narcotics. The results come back negative because the screen will pick up neither methadone nor Xanax. Misled by the test results, the doctor does not prescribe a medicine that would blunt symptoms of withdrawal as the narcotic wears off—and that decision has fatal consequences. “Suddenly [the patient] starts vomiting from opiate withdrawal but doesn’t wake up, because he has OD’d on benzodiazepines,” Prosser says. Inhaling that vomit could kill him.

Improved testing is not necessarily the answer, Mycyk says. When time is critical, taking note of a telltale constellation of symptoms typically triggered by a certain class of drugs—and treating those symptoms—makes more sense than waiting for chemical confirmation.

Federal organizations have started to work on solutions as well. Last July the Food and Drug Administration began requiring drug companies to start educating doctors about the special risks of such prescription drugs. The CDC has called on states to consider monitoring Medicaid or workers’ compensation claims “for signs of inappropriate use of controlled prescription drugs.” To help reduce doctor shopping, the CDC says, these state programs might in some cases consider restricting reimbursement for controlled drugs to scripts that come through only one designated prescriber per patient and one designated pharmacy.

Mycyk has started telling the ER physicians he trains that they might save more lives by asking more specific questions than the ones they learned to ask in medical school. “Don’t ask, ‘Do you abuse illegal drugs?’ ” he says. “Most of the drugs people are using today are not illegal. A lot of them are overdosing on drugs that were prescribed by their doctor.”

Instead, Mycyk says, asking questions such as “Have you ever gotten high on cough syrup?” or “Have you ever taken a friend’s or relative’s pills?” will put you on the right track to more helpful responses. “Most [patients] will do all they can to help you,” he says. “In most cases, landing in the ER was an accident. They don’t want to die.” SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/oct2012

David Pogue is the personal-technology columnist for the *New York Times* and host of *NOVA scienceNOW*, whose new season premieres in October on PBS.

Rent Out Your Hot Button

Want to save money and prevent power outages? Get your thermostat a digital remote control

This is a story about technology, science and goodwill coming together in a way that benefits everybody and costs nobody. Sound improbable? Well, it gets better. The architect of this arrangement is, if you can believe it, a municipal utility.

It's Con Edison—New York City's electric company.

Con Ed is offering its customers an Internet-connected thermostat. It's smart, simple—and you can control it online or via a smartphone.

For example, you can adjust your home's heat or air-conditioning as you return from a trip to make it comfortable when you arrive. Or if you forget to turn off the AC, you can do it with a couple of taps on your phone.

You don't even need home Internet service for this setup. The thermostat communicates with the Internet on a frequency reserved for those old pocket pagers. Sneaky!

But what if, like most New Yorkers, you have a window air conditioner instead of central air?

For you, Con Ed offers a new kind of thermostat. This smart AC kit, from a company called ThinkEco, resembles a short extension cord. Once you plug your AC into it, you can use the included remote control within your apartment. (The remote also measures room temperature.) In addition, the kit comes with a USB transmitter stick that plugs into your computer and borrows its Internet connection for the air conditioner's use. This allows you to program your window unit from a Web site or a phone app.

The best part, though, is that all of this is free. Actually it's better than free: sign up and use either of these thermostats, and Con Ed also gives you a $25 gift card.

Have they lost their ever loving minds?

Not quite. It turns out that there's a beautiful catch.

You're not the only one who will have control over your AC. During what industry insiders call "peak usage events"—the most sizzling hot days—Con Ed can dial back your AC from its office.

Yes, it sounds like Big Brother is warming you, but it's not as bad as it sounds. Con Ed adjusts your temperature by only two or three degrees. (And last year it did so only twice.) Plus, it warns you in advance by phone, e-mail or text message. Most reassuringly, you can override the override. If you don't like how Con Ed tweaked your temp, you can dial it right back again.

Isn't Con Ed in the business of *selling* electricity? Why would it go to such lengths to get you to consume less of it?

Imagine if thousands of customers installed these thermostats. If Con Ed can throttle back their AC en masse, even just a notch or two, New York might avoid a brownout or a blackout.

For Con Ed, there's a bigger payoff: infrastructure cost savings. As the population grows and demand rises, Con Ed has to install more equipment. More substations, more cables. If Con Ed can delay those expenditures by two or three years, this free-thermostat program will have been a shrewd investment.

Con Ed and other utilities have offered similar deals to commercial customers for years. "During a demand-response event, we can take one or two elevators out of service," says Con Ed's Adrianne Ortizo, who runs these programs. "We can turn down common-area lighting. If the HVAC is connected, we can also cycle those systems on and off." In exchange, building managers enjoy discounts for power and equipment.

Yet bringing this offer to individuals is an overwhelmingly powerful idea. Cutting back on power improves air quality. The utility delays those huge capital expenditures. The city avoids a blackout. And you get a cool-looking thermostat you can control with a free app.

Now, there are six million air conditioners in Con Ed's territory. So far 23,000 customers have signed up for the thermostat; Con Ed aims to distribute 10,000 more this year. Together they could save five megawatts—on a day when the city typically consumes *13,000* megawatts. That's the tiniest drop in a very big bucket.

But never mind. Every great idea has to start somewhere. SA

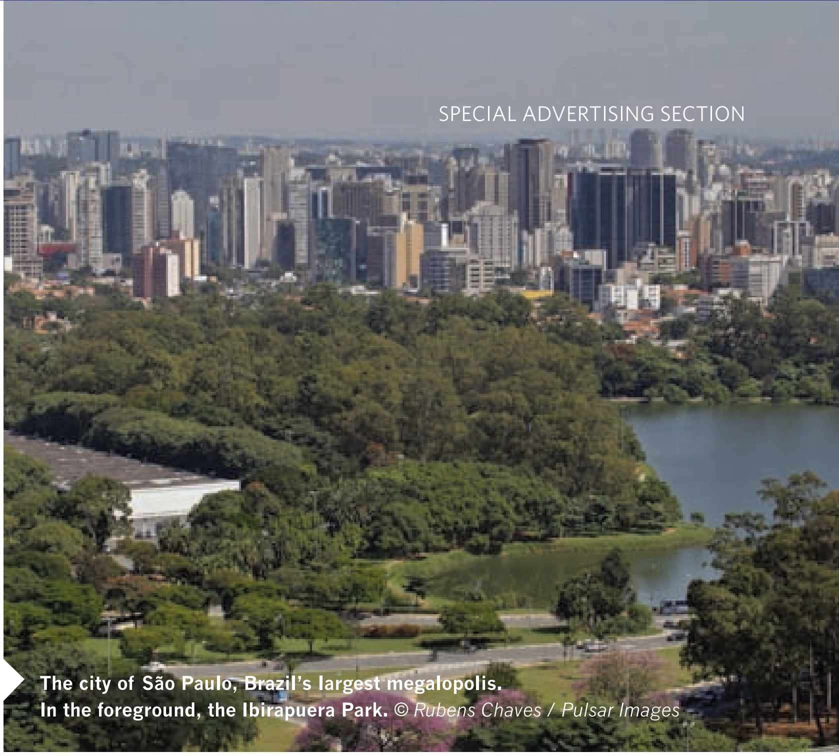
SCIENTIFIC AMERICAN ONLINE
Three systems to control temp from afar: ScientificAmerican.com/oct2012/pogue

Illustration by Nick Stokes

SÃO PAULO RESEARCH FOUNDATION

BRAZILIAN SCIENCE, OPEN TO THE WORLD

FAPESP



The city of São Paulo, Brazil's largest megalopolis.
In the foreground, the Ibirapuera Park. © *Rubens Chaves / Pulsar Images*

HALF OF BRAZIL'S SCIENCE OUTPUT IS FROM SÃO PAULO

For 50 years, FAPESP has been supporting research in the State

Brazil is emerging as a major contributor to scientific knowledge. In 2011, the country stood fifteenth in terms of the number of scientific papers published, a position that will be boosted in years to come by the twelve thousand new doctorates that are graduating annually.

More than half of the country's scientific output is concentrated in the State of São Paulo, which is also Brazil's economic powerhouse. With almost 42 million inhabitants, the state accounts for 35 percent of Brazil's gross domestic product (GDP), outstripping countries like Belgium, Norway, Poland, and even the Netherlands.

At the heart of the state's progress in science is FAPESP, the São Paulo Research Foundation. Created in 1962, FAPESP is a dynamic research-funding agency. Over the past half century, it has supported the training of 112,000 scientists from undergraduate to postdoctoral level, provided financial backing to 96,000 individual and thematic research projects, and funded substantial improvements to the research infrastructure.

Currently, more scientific articles are published by researchers from the state of São Paulo than from any country in Latin America, other than Brazil as a whole. And, with 1.52 percent of GDP being invested in R&D, a figure that surpasses Spain, Italy, Portugal, Mexico, Argentina and Chile, the science sector in the state will continue to develop strongly.

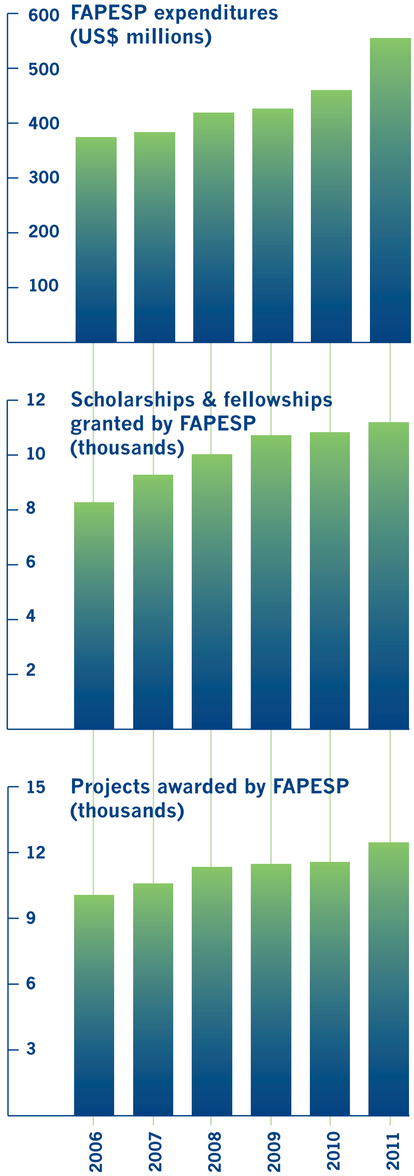
Five major state- and federally-funded universities are located in the State of São Paulo, The University of São Paulo (USP), The State University of Campinas (UNICAMP), The São Paulo State University (UNESP), The Federal University of São Paulo (UNIFESP), The Federal University of ABC (UFABC) and The Federal University of São Carlos (UFSCar).

The three state universities – USP, UNICAMP and UNESP – have particularly strong graduate programs. Every year, two thousand doctorates graduate from USP, eight hundred from UNICAMP and six hundred from UNESP.

The state also hosts nineteen research institutes, including the Aeronautics Technology Institute (ITA), the National Space Research Institute (INPE) and the National Synchrotron Light Laboratory (LNLS)

US$554 MILLION FOR SCIENCE IN 2011

FAPESP enjoys full administrative and financial control over one percent of the State's tax revenue, guaranteed by the State Constitution. In 2011, this generated a research budget for FAPESP of some US$554 million to support all areas of fundamental and applied science as well as technology, engineering, humanities and arts. Evaluations for funding are based on rigorous and confidential peer review of scientific merit.



FAPESP blossomed in the 1990's, after the end of military rule (1964-1985) and the restoration of democracy in Brazil, and reached full maturity with a highly successful genome program. This began in 1997 with the sequencing of the bacterium *Xylella fastidiosa* (which causes the disease of citrus fruits known as "yellow"), a study that made the cover of *Nature*. It continued with the sugarcane genome program, which was initiated in 1998 and positioned Brazilian science at the forefront of genomics.

Almost 250 researchers around the country participated in the Sugarcane Genome Project, identifying nearly 50,000 genes involved in growth, sugar production, disease resistance and survival in adverse climate and soil conditions. The sequencing of the *Xanthomonas citri* bacterium, which causes citrus canker, another disease of orange trees, and the Cancer Genome Project, were also great successes of the Genome Program.

With the FAPESP Genome Program, the Foundation proved itself capable of organizing large, multidisciplinary research programs that have immediate economic and social impact. It provided first-hand experience of the high degree of integration required for scientific and technological research on a global scale and introduced the country's research base to international cooperation. Building on this success, FAPESP is committed to establishing partnerships and agreements with funding agencies, higher education and research organizations, and companies from different countries.

The Foundation seeks to promote research in areas considered strategic for the country and crucial for the advance of world science. Ambitious programs are being supported in bioenergy (BIOEN), biodiversity (BIOTA) and global climate change (RPGCC), among other areas. » **www.fapesp.br/en**

ON THE COVER: The city of São Paulo, capital of the state of São Paulo. © *Delfim Martins / Pulsar Images* **Atlantic Forest, protected reservation in the municipality of Gália, state of São Paulo.** © *Eduardo Cesar*

Facade of the headquarters of FAPESP, in the city of São Paulo © *Eduardo Cesar*

INTERNATIONAL PARTNERSHIPS & AGREEMENTS

UNITED STATES: National Science Foundation; Fulbright Foundation – Dr. Ruth Cardoso Program; Oak Ridge National Laboratory; Massachusetts Institute of Technology; North Carolina State University; University of California – Dr. Ruth Cardoso Program; University of Southern California; Agilent Technologies; Boeing; Microsoft Research.
CANADA: Agence Universitaire de la Francophonie; International Science and Technology Partnerships; National Sciences and Engineering Research Council of Canada; Consortium of Alberta, Laval, Dalhousie and Ottawa; McMaster University; University of Ontario Institute of Technology; Simon Fraser, Concordia, York and Ryerson Universities; Toronto and Western Ontario Universities; University of Victoria.
UNITED KINGDOM: British Council; Research Councils United Kingdom; King´s College London; University of Nottingham; University of Surrey; University of Southampton; Bangor University; Institute of Education University of London; University of Edinburgh; University of York; Imprimatur Capital.
FRANCE: Agence Nationale de la Recherche; Centre National de la Recherche Scientifique; Région Provence-Alpes-Côte d´Azur; Centre de Coopération Internationale en Recherche Agronomique pour le Développement; Ecole Normale Supérieure; Institut National de la Recherche Agronomique; Institut National de Recherche em Informatique et en Automatique; Institut National de la Santé et de la Recherche Médicale; Paris-Tech.
EUROPE: Worldwide LHC Computing Grid.
GERMANY: DAAD, German Academic Exchange Service; DFG, Deutsche Forschungsgemeinschaft; and STMWFK, The State Ministry of Sciences, Research and The Arts of the Free State of Bavaria .
NETHERLANDS: Bio-based Ecologically Balanced Sustainable Industrial Chemistry; Erasmus Universiteit Rotteerdam.
DENMARK (Danish Council for Strategic Research).
SPAIN (Universidad de Salamanca).
ARGENTINA (Consejo Nacional de Investigaciones Científicas y Técnicas).
MEXICO: Instituto de Innovación de Nuevo León
ISRAEL (The Hebrew University of Jerusalem; Tel Aviv University).

» **www.fapesp.br/en/agreements**

FAPESP BIOENERGY RESEARCH PROGRAM (BIOEN)

Clean, renewable resources already provide 46 percent of the total domestic energy matrix. Today's research program will yield further gains.

Brazil is internationally recognized for leadership in the use of bioethanol as an alternative to gasoline. Today, sugarcane ethanol provides more than 40 percent of the fuel consumed by light vehicles in the country and the thermal energy and electricity produced using ethanol and sugarcane bagasse, which is the fibrous matter that remains after stalks are crushed to extract their juice, meets 18 percent of domestic energy needs. Due to these and other factors, the Brazilian energy grid provides an exemplary case of sustainability: 46 percent of the country's energy matrix is generated from clean, renewable resources, compared with an average of just 13 percent for all countries.

Favorable soil and climate conditions mean that Brazil is the largest global producer of ethanol and sugar from sugarcane. Currently, sugarcane is cultivated on 7 million hectares (ha), which is 2 to 3 percent of the total area devoted to agriculture. The country is also the world leader in production technology as a result of long-term R&D programs in universities, research institutions and the private sector, where both growers and mill owners have supported research. At present, the average sugarcane yield at is 75 tons/ha but recent studies indicate a theoretical potential of 380 tons/ha. Biotechnology research and the development of more efficient agricultural practices will be applied to drive gains in yield.

The program team numbers over 300 researchers from 16 institutions of higher education and research.

The operating model for the industry is to produce sugar for bioethanol production and to generate bioelectricity, which can be sold to the national energy grid. Modern production plants are increasing output and lowering costs by using the bagasse surplus to increase ethanol production without increasing the cultivated area.

While the Brazilian sugar and ethanol industry leads the world, great challenges lie ahead in the future. Second and third generation biofuels, as well as environmental and sustainability issues, demand continuous research and the development of novel tools. FAPESP, through its BIOEN Research Program, is an important part of the Brazil's endeavor to maintain leadership in clean and sustainable bioenergy.

INTEGRATING PUBLIC AND PRIVATE R&D

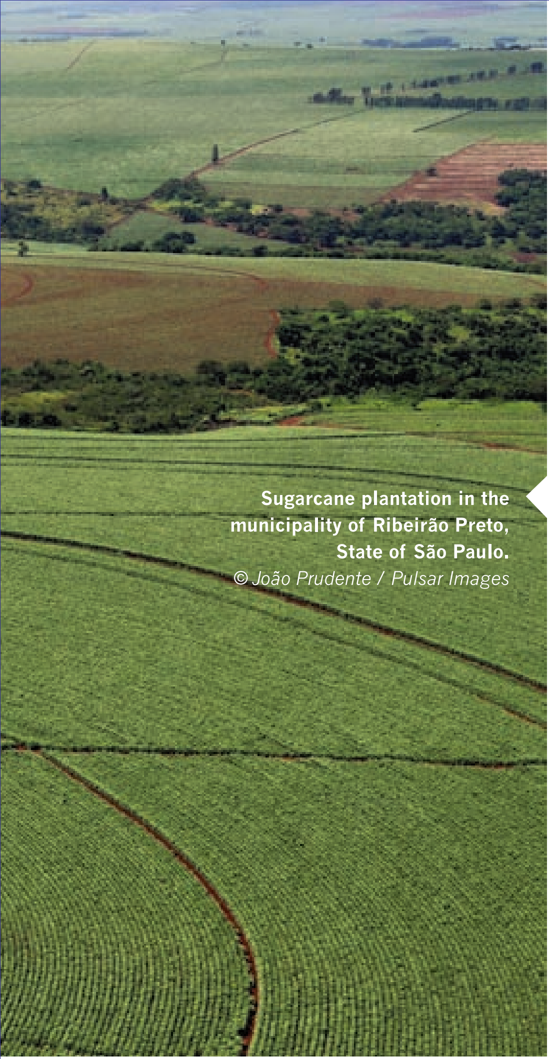
Begun in 2008, the FAPESP Bioenergy Research Program (BIOEN) stimulates and coordinates research and development in academic and industrial settings to advance knowledge and its application in areas related to bioenergy production.

The Program is organized into five divisions:

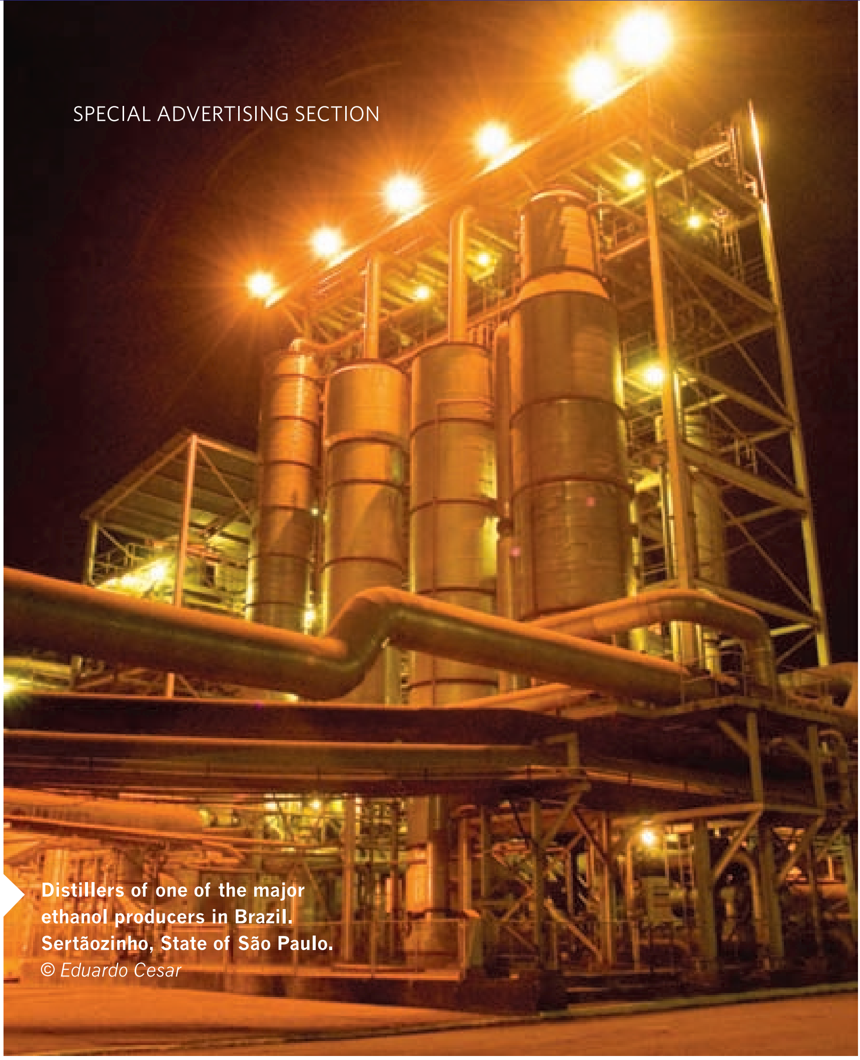
- Biomass Research (including plant improvement and sugarcane farming.)
- Ethanol and Biofuel Industrial Technologies.
- Biorefinery Technologies, Alcohol Chemistry, Sugar Chemistry and Oil Chemistry.
- Ethanol Applications for Motor Vehicles and Aviation Fuels.
- Research on Impacts, specifically social, economic and environmental studies; land use; intellectual property, institutional bottlenecks of a bio-based economy.

The program team numbers over 300 researchers from 16 institutions of higher education and research in the state of São Paulo. It is guided by six strategic goals, which are:

- To increase sugarcane yield through the use of novel practices, breeding and biotechnology.
- To increase ethanol production through optimization of existing, first generation process and the development and implementation of new technologies for first, second and third generation ethanol production processes.
- To increase the production of bio-based chemicals for the substitution of petrochemicals. To evaluate and mitigate



Sugarcane plantation in the municipality of Ribeirão Preto, State of São Paulo.
© João Prudente / Pulsar Images



Distillers of one of the major ethanol producers in Brazil. Sertãozinho, State of São Paulo.
© Eduardo Cesar

the environmental, social and economic impact of bioenergy production.
- To develop a suitable platform for biorefineries based on sugarcane and ethanol as feedstock.
- To generate knowledge that guarantees Brazil´s leading position in the global bioenergy research and industry.
- In partnership with private companies, BIOEN's research agenda includes biomass production and processing; the production of biofuels; the development of engines; alcohol chemistry applications; and environmental and socioeconomic impacts. The program supports 84 basic research projects and applications for sustainable production of biofuels that are based on, but not limited to, sugarcane ethanol. Fifteen of the projects include research collaborations with other countries. » **www.fapesp.br/en/bioen** » **www.bioenfapesp.org**

BIOTA-FAPESP PROGRAM

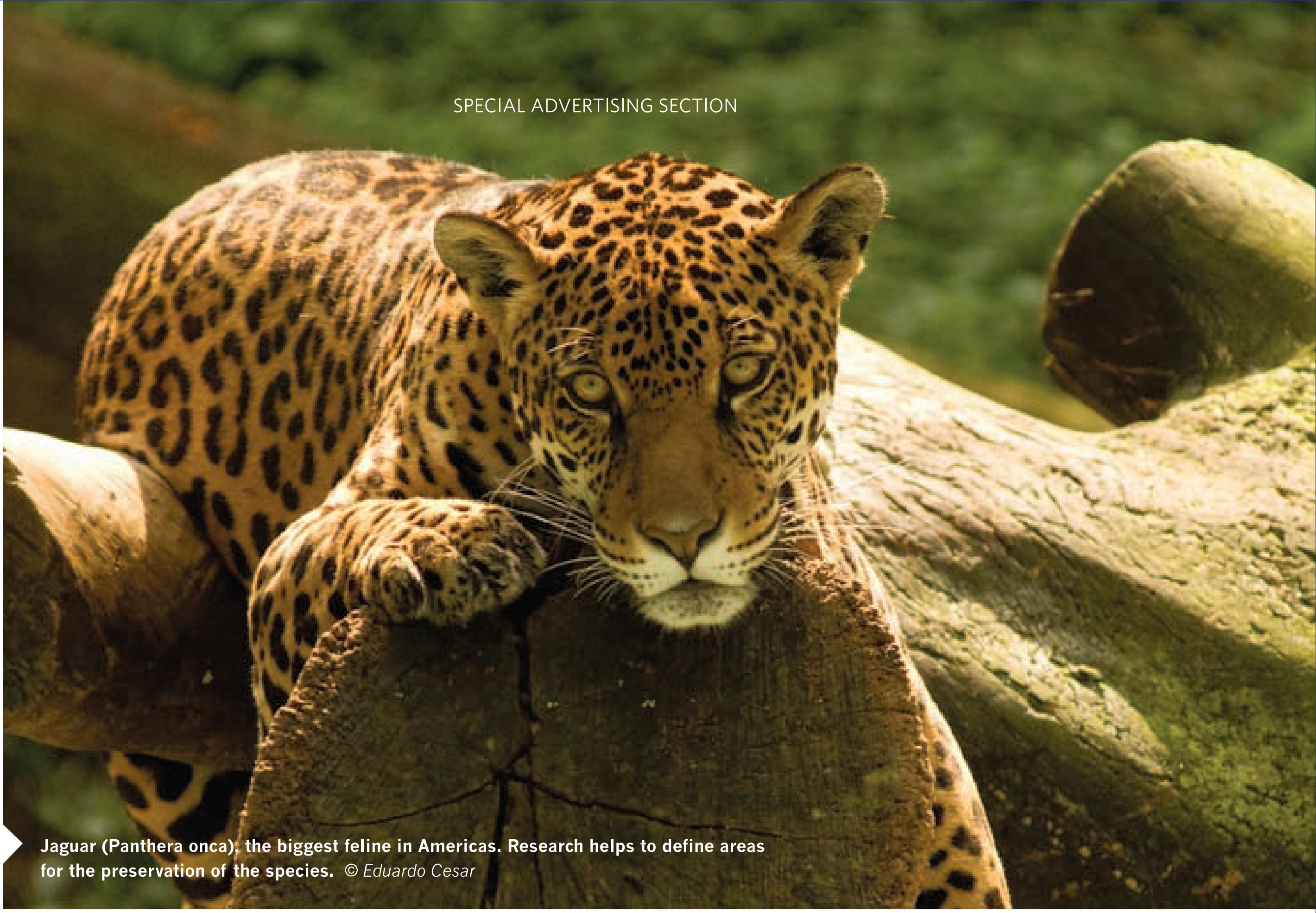
1,800 new species of plants and animals have been catalogued.

Brazil has incredible natural resources. Home to between 15 and 20 percent of the planet´s biodiversity, the country encompasses six large biomes — Amazonia, Caatinga (scrubland), Atlantic Forest, Cerrado (savannah), Pantanal (wetlands) and Pampa (grassland) — originally distributed across 8.5 million square kilometers of the continent and more than eight thousand kilometers of coastline. Despite intense urbanization and the high density of occupation and use of the land, the State of São Paulo, located in southeast region of Brazil, possesses an extremely rich biological diversity. For example, the number of plant species within São Paulo territory amounts to two-thirds of that found in the entire European continent.

The BIOTA-FAPESP Program was created in 1999 with the principal objective of cataloguing and characterizing the biodiversity of the State of São Paulo, defining the mechanisms for its conservation, evaluating its economic potential and stimulating its sustainable use.

For more than 10 years, the BIOTA-FAPESP Program has been a major conservation initiative that is founded on a solid scientific basis. Research projects include:

- The molecular genetics for classification of species.
- Evolution studies to understand the origin of processes that generate, conserve or reduce biodiversity.
- Investigation into human dimensions of conservation and sustainable usage.



Jaguar (Panthera onca), the biggest feline in Americas. Research helps to define areas for the preservation of the species. © *Eduardo Cesar*

Scientists participating in the program have published nearly 900 scientific articles, 20 books and two atlases, and have catalogued more than 1,800 new species of plants and animals. The program has drafted maps which identify conservation areas based on 151,000 records of more than 9,000 species. Based on this body of knowledge, the São Paulo legislation has made 14 decisions on conserving threatened biomes.

The databases of the Biota-FAPESP Program are open to the scientific community. The Environmental Information System, SinBiota (www.sinbiota.biota.org.br), registers and integrates the geographical coordinates of thousands of species of plants and animals in the State of São Paulo. This database can be queried using the scientific name of a plant or animal, the name of the collector, or the locality or date of collection.

It is also possible to see the geographical distribution of species since SinBiota is a cartographic-based system that details remnants of native vegetation, areas reforested with exotic species (such as Pinnus and Eucalyptus), conservation units, the river and road networks, and the urban areas. A second database, the Biota-FAPESP Program Atlas incorporates the Forest Inventory of São Paulo, which is a survey coordinated by the Forestry Institute. Generated using field surveys, aerial photos and satellite images, the inventory monitors the area occupied by remnants of native vegetation in the State of São Paulo.

Based on knowledge generated by the BIOTA program, the São Paulo legislation has made 14 decisions on conserving threatened biomes.

A third database, Species Link (www.splink.cria.org.br), has aggregated two million records from research activities or imported from the archives of national and foreign biological collections.

Other developments of Biota-FAPESP are the electronic scientific magazine Biota Neotropica (www.biotaneotropica.org.br), which publishes studies on biodiversity in the Neotropical region, and the Biota Network of Bioprospecting and Biotrials (www.bioprospecta.org.br), which integrates the work of research groups in the State of São Paulo that are engaged in economic development projects based on microorganisms, macroscopic fungi, plants, invertebrates (including marine) and vertebrates.

In 2009, FAPESP renewed funding of the BIOTA-FAPESP program for another 10 years, with a view to prolonging and enhancing the results and scope of the work. Named “BIOTA + 10”, one of the strategic goals of the program is the expansion of multidisciplinary research on marine biodiversity. Brazil

has a coastline of around 8,000 km and an adjacent continental shelf of over 800,000 km^2. This contains an array of ecosystems and environmental settings that harbor substantial marine biodiversity, nowadays referred as "Blue Amazonia." Currently, little is known about this fantastic biological resource.

Among the topics proposed for BIOTA + 10 are inventories of marine organisms and the identification of environmental factors that affect their distribution and abundance; studies of marine ecosystems and the impact of oil and gas exploitation upon them; and analyses of marine biodiversity that might be incorporated into climatic change models.

One goal of such a marine inventory is the provision of data to inform laws regarding the protection of diverse marine biomes. At the same time, the program also emphasizes bioprospecting for marine natural products – mainly bioactive compounds for pharmaceutical production. The research will help to promote informed debate on the sustainable use of Brazilian marine biodiversity resources.

» **www.fapesp.br/en/biota**

FAPESP RESEARCH PROGRAM ON GLOBAL CLIMATE CHANGE (RPGCC)

The goal is to develop a Brazilian model of the global climate system, by 2013.

Tower of the Large Scale Atmosphere-Biosphere Experiment in Amazonia, used to measure long-term trace gasses and aerosols.
© Paulo Artaxo Archive

There are four key drivers of climate change research in Brazil. First is the continental-sized dimensions of the country. Second is the dependence of the economy on renewable natural resources. Third is the fact that the vegetal cover has been significantly altered in the Atlantic Forest and the Cerrado, and is quickly being replaced in Amazonia. And fourth is the increased emissions of greenhouse gases and aerosols resulting from the combustion of fossil fuels and industrial and agricultural processes. A bold study that encompasses and relates all of these variables is essential for public policy in areas such as risk assessment, mitigation of effects, and adaptation to the changes.

The FAPESP Research Program on Global Climate Change (RPGCC) is just such an initiative, supporting multidisciplinary research projects for up to six years. One of the major goals is a Brazilian model of the global climatic system by 2013, with a focus on key regions including the Amazon, the Cerrado and the South Atlantic regions.

The Program combines observation and modeling components, and includes long-term environmental measurements as well as the generation of paleoclimate data, a crucial requirement to overcome the lack of long-term environmental observations. The FAPESP program is delivered in association with other funding mechanisms, both internal and external to the State of São Paulo.

The RPGCC also has a substantial technological component for the development of the appropriate technologies for a sustainable future. This encompasses innovative technologies for the mitigation of emissions and adaptation in all sectors and economic activities, given that climate change is inevitable and societies must adapt their socio-economical systems to these changes. The Program also includes a research component on the interface between earth science and climate policy.

The RPGCC considers proposals for research which fall within the scope of the Program described above, in particular in the following areas:

- Consequences of global climate change to the functioning of ecosystems, with emphasis on biodiversity loss and water, carbon and nitrogen cycles.
- Changes in the atmospheric radiation balance, including the effects of aerosol particles, clouds, trace gases and land use change.
- The impact of global climate change on agriculture productivity and food security.
- Energy production and the mitigation of greenhouse gases emissions.
- The impact of climate change on human health.
- Human dimensions of global climate changes: impacts, vulnerabilities and social and economic responses, including adaptation strategies.

Development of the Program is facilitated by a high performance supercomputer, provided jointly by FAPESP and the Science and Technology Ministry. The massive processing capacity positions the program among the world's most important for climate studies, with the capacity to create and analyze global climate models. The equipment—named Tupã, in reference to the god of thunder in one of the native Brazilian mythologies—has a peak performance of 244 teraflops

(trillions of floating point operations per second).* The system incorporates recent advances in numerical modeling, climate change modeling, data assimilation, chemicals and aerosols, atmosphere, oceans and vegetation.

The model will be used to analyze interactions between the multiple elements of the terrestrial system to understand the influence of anthropogenic actions – such as greenhouse gas and aerosol emissions, changes in vegetation and the effects of urbanization on climate. Studies on the nitrogen and carbon cycles in nature and their impact on agriculture and livestock are also among the research topics.

The environment of the Amazon is an extremely important aspect of the project. It represents a very dynamic and complex system, and, to understand it, researchers need to comprehend the main processes that govern its functioning, such as the carbon balance and changes in the aquatic systems. » **www.fapesp.br/en/rpgcc**

**The flop (floating point operations per second) is the unit of computer performance. For comparison, an ordinary four operations calculator has a performance of 10 flops.*

OPPORTUNITIES FOR POSTDOCS & YOUNG RESEARCHERS

Young researchers are strongly encouraged by FAPESP programs. © *Eduardo Cesar*

FAPESP has ongoing programs and support mechanisms to attract scientific researchers from overseas. The research positions are in a wide range of projects developed in the São Paulo Centers of Excellence. The greatest number of opportunities for foreign scholars to participate in postdoctoral research is in Thematic Projects in which experienced scientists, many of whom are renowned leaders in their field, collaborate for up to six years. In 2011, FAPESP spent US$ 45 million supporting Thematic Projects. Scholarships of up to US$ 34,000 annually for up to four years are available in all Thematic Project areas. A list of the 1,452 Thematic Projects that have been or are currently supported by the foundation can be found on the website: » **www.bv.fapesp.br/en/1/thematic-projects.**

Information regarding open opportunities can be accessed at: » **www.fapesp.br/oportunidades.**

Young Investigators Awards also offer funding of up to US$ 38,000 per annum. Recent graduates who have produced relevant scientific findings and who have feasible, solid and innovative proposals can use the award to collaborate with research teams at existing São Paulo centers or can form new groups in institutions in the State that do not have a research tradition in the particular subject. In 2011, FAPESP's commited US$ 21 million to the program. Further information is available at: » **www.fapesp.br/en/yia.**

STATE OF THE W

A MEASURE OF THE CREATIVITY OF A NATION IS HOW WELL IT WORKS WITH THOSE BEYOND ITS BORDERS

By John Sexton

WHEN MIKHAIL GORBACHEV FREED ANDREI SAKHAROV TO TRAVEL TO THE U.S., ONE OF the Russian nuclear physicist's first stops was the New York Academy of Sciences. Members of the academy's Board of Governors at that time, in 1988, had been leaders in mobilizing the scientific community to fight for Sakharov's freedom, and Sakharov wanted to extend his thanks for all their efforts.

The story shows how much the world has changed—particularly the scientific world—in the past quarter of a century. At the time of Sakharov's release, only a handful of countries pursued serious scientific research, and still fewer permitted scientific study independent of state interests. Researchers, to the extent that their work required them to collaborate with colleagues beyond national borders, had to scale high boundaries to do so. Today things are quite different.

Globalization (which I sometimes call "planetization" to signal a phenomenon more comprehensive than "globalization" denotes for some) is a defining characteristic of this era in human history. It is not new. In 2004 historian John Coatsworth described globalization as "what happens when the movement of people, goods, or ideas among countries and regions accelerates," and that process has been carrying on in one form or another since modern humans first ventured out of Africa. Something different is happening now, however: the world is miniaturizing. It is no longer possible to keep out the economic, political, cultural or intellectual effects of actions taken in distant lands. Global society operates as a network of creativity and innovation, with a set of "idea capitals" forming the principal nodes of this network. If in the Italian Renaissance, the talent class moved among Milan, Venice, Florence and Rome, today our most creative and innovative citizens move easily among Silicon Valley, Shanghai, London and New York City.

From Aristotle to Stephen Hawking, scientists always have sought to operate beyond sovereignty; indeed, science inherently resists the confinement of boundaries. Copernicus's theories of the solar system led to Galileo's astronomical discoveries, which paved the way for Newton's theory of universal gravitation. Remember, however, that these intimately related breakthroughs occurred over a span of centuries. For most of history the development of scientific understanding was steady but slow, a function of the physical distance between scientists, restricted educational opportunity, lack of resources and political interference. Today the pace of innovation has accelerated drastically.

Indicators of research activity bear witness to an explosion of scientific capacity and a strong trend toward international collaboration. Consider these statistics: in 1996 about 25 percent of scientific articles were written by authors from two or more countries; today the number is more than 35 percent. The share of publications produced by American scientists in collaboration with scientists from other countries increased from 16 percent in 2006 to

TOGETHERNESS: This circular graph shows collaboration among the 25 nations with the largest science output, as measured in scientific papers that appeared in 2011 in a select group of journals. Not included are collaborations that took place inside each country.

RLD'S SCIENCE

SOURCES: DIGITAL SCIENCE; MARTIN SZOMSZOR *Digital Science (preliminary data)*

Graphics by Sven Laqua and Arno Ghelfi

30 percent in 2008. In 2008 Chinese scientists were publishing almost six times as many scholarly articles as they did in 1996; today about 10 percent of the world's articles come out of China. In 1989 South Korea did not rank in the top 10 countries filing patent registrations at the U.S. Patent and Trademark Office. Now it ranks third. Since 1995 Turkey has increased its R&D spending by nearly six times and the number of researchers by 43 percent. The list goes on, and all the numbers lead back to the simple fact that there has been a seismic change in the scope and reach of scientific research across national boundaries and within countries not previously represented in major science.

Although the life of the scientist may not be consciously global, the enterprise of science is permeated by globalization in several distinct forms. The base of it—and a good part of the substance of it—is so eminently simple that it could go unnoticed: the speed and ease with which we now communicate have so accelerated the flow of ideas that the scientific enterprise is more interconnected than ever before. And while this greater connectivity has not altered the basic quest—the pursuit of knowledge and the advancement of humankind—the increased globalization of scientific research has created a more open intellectual ecosystem that draws more smart people into the conversation.

For instance, one great recent advance in the fight against malaria is a drug called artemisinin. Just last September the Lasker-DeBakey Clinical Medical Research Award was given to one of the Chinese scientists who led the development of this drug. Artemisinin, however, was actually discovered in China around 40 years ago at the personal request of Chairman Mao Tse-tung, who was seeking to help North Vietnam in its war with the U.S. The isolation of China and its scientists delayed the worldwide awareness of this crucial discovery by seven years—and delayed its availability many years beyond that. And in the 1940s German-American biophysicist Max Delbruck and Italian microbiologist Salvador Luria collaborated on their famous experiment showing that bacterial resistance to viruses is genetically inherited. This was profound work, and they communicated through the most reliable, effective collaborative tool of their day: the post office.

Today, through the Internet and social media, we understand community in a different way; we are more accustomed to coming into intellectual contact with strangers, we are able to expand the pool of talent in new and more successful ways, and we have much deeper relationships with our collaborators. The scientific descendants of these stories most likely use Skype, Facebook or shared networks—or a combination of all three. The volume of data is far more rapid; more colleagues—even nonscientists—are part of the conversation; and the volume of data able to be collected, reviewed and processed is comparatively massive. These differences redefine the concept of collaboration and colleagueship. New York University scientists in mathematics and neuroscience at the New York campus work nearly as closely with their colleagues at our campuses in Shanghai and Abu Dhabi as they do with their colleagues down the corridor, and they share results from the most advanced equipment across campuses.

As a result of interconnectedness, location matters less than ever before. A study of how people process language differently is necessarily made more robust by being conducted in multiple locations. Researchers based in New York City can pursue a study that requires a highly sensitive device for measuring magnetic fields of the brain—despite the potentially disruptive effect of the subway system—by locating the device in another country. No matter what the specific project, scientists in multiple locations around the world can overcome the restraints of the workday. Researchers are extraordinarily hardworking, often visiting their laboratories at night or forgoing vacations while an experiment is being conducted. By operating labs in different time zones, the constraints of time can be overcome, work can continue around the clock and results can be produced more quickly. Increasingly, teams of scientists are using the world's time zones to make their work easier.

The ability to communicate faster regardless of distance has profoundly altered the research agenda. Topics have surfaced that heretofore had not existed or had not been examined. This category includes climate change, food security and humanitarian issues such as water engineering and tropical illnesses. On a sovereign national research agenda, these areas might receive second- or third-tier attention; however, they are top priorities on a global research agenda. Thus, it is not simply that the speed and ease of rapid communication have made the creation of international research teams easier; it also is that the creation of those teams has shaped the questions asked, thus bringing humankind's interconnected challenges to the foreground of scientific attention.

John Sexton was named the 15th president of New York University in 2001. He was chair of the Board of Governors at the New York Academy of Sciences from 2007 to 2011 and is now chair emeritus.

To pursue many of these research projects in the most expeditious way, there is no substitute for true global study. Ocean sea levels and the pressing challenges of managing cities in an increasingly urban world cannot meaningfully be studied except on the enormous scale that globalization allows. Such projects demand that data be collected from around the world, and they marshal brainpower and resources in a way that would have been unimaginable a mere quarter of a century ago. Such undertakings have the complexity of a great symphonic crescendo. Were it not for the tremendous capacity now in place—the sometimes unnoticed change in the way of doing things, the additional actors who can be brought in, the ability to break through space and time—we could not have this kind of dense research. It is like creating one observer's eyes out of many.

In the pursuit of all these research projects, with the enlargement of more and more talent from around the globe and the easy flow of information to support collaboration, the world's scientific community has become less dependent on the U.S. and the West. Many countries now see investment in science and technology as the way to build their economy; the result is larger R&D budgets, which, in turn, are producing more robust academic collaborations with international colleagues. For exam-

SOURCE: NYU PHOTO BUREAU/MADERE

ple, the number of science and engineering Ph.D.'s awarded at Asian universities, especially in China, is increasing, whereas the number awarded in the U.S. is decreasing. Fifteen years ago the U.S. published more than 10 times as many scientific papers as China, and Chinese scientists were almost invisible in scientific journals. Two years ago China ranked second in the world in published papers; it could overtake the U.S. by next year. During the past decade China, India and Brazil more than doubled their expenditures on research and development—increasing their contributions to world R&D spending from 17 to 24 percent. A 2010 report by the U.S. patent office showed that American dominance of patents issued by the U.S. ended in 2008, when patents of foreign origin surpassed those originating in the U.S. And a Thomson Reuters report showed that China surpassed the U.S. and Japan in new patent applications last year.

This intensified activity around the world has certainly been to the good. Globalization, as manifested in international collaboration on "big science" projects, is now taken for granted. The Human Genome Project, the International Space Station, the Large Hadron Collider at CERN near Geneva and ITER (formerly the International Thermonuclear Experimental Reactor) in France are only a few examples. The globalization of science has been a boon for humanity.

We should be cautious, however, about overly congratulating ourselves. Although scientists have become ever more able to reach out to one another and the scientific community has become ever more cohesive, there are considerable risks and challenges. Many stem from a great tension of our time: as the world grows more connected, individuals and institutions have sought out new ways to draw boundaries.

Despite how much more encompassing the conversation about science may be and how many more people we involve, many are still excluded. Throughout the world there are those with little or no access to the telecommunications revolution or the Internet, much less to advanced education or technical knowledge. As long as these conditions continue, we will have too many people of talent absent from important conversations. The real danger is that this trend is self-reinforcing and that the gap in scientific capacity between developed and less developed nations will widen.

MANY COUNTRIES SEE SCIENCE AND TECHNOLOGY AS A WAY TO BUILD THEIR ECONOMY. THE RESULT IS LARGER R&D BUDGETS.

Similarly, we need to guard against losing our ability to hear the voices of those at the margins who challenge orthodoxies—some of our greatest breakthroughs have come from that quarter. Put another way, we need to be mindful of the perils of "groupthink" or "fast-think." Whereas new technologies bring scholars, researchers and even nonscientists together in remarkably efficient and beneficial ways, these media and new virtual communities may reinforce conventional wisdom. With the same goal in mind, we will also need to have clearer understandings about intellectual property. Pervasive suspicion that the fruits of research will not be properly respected in other locations could have a devastating impact on collaboration and the development of new concepts.

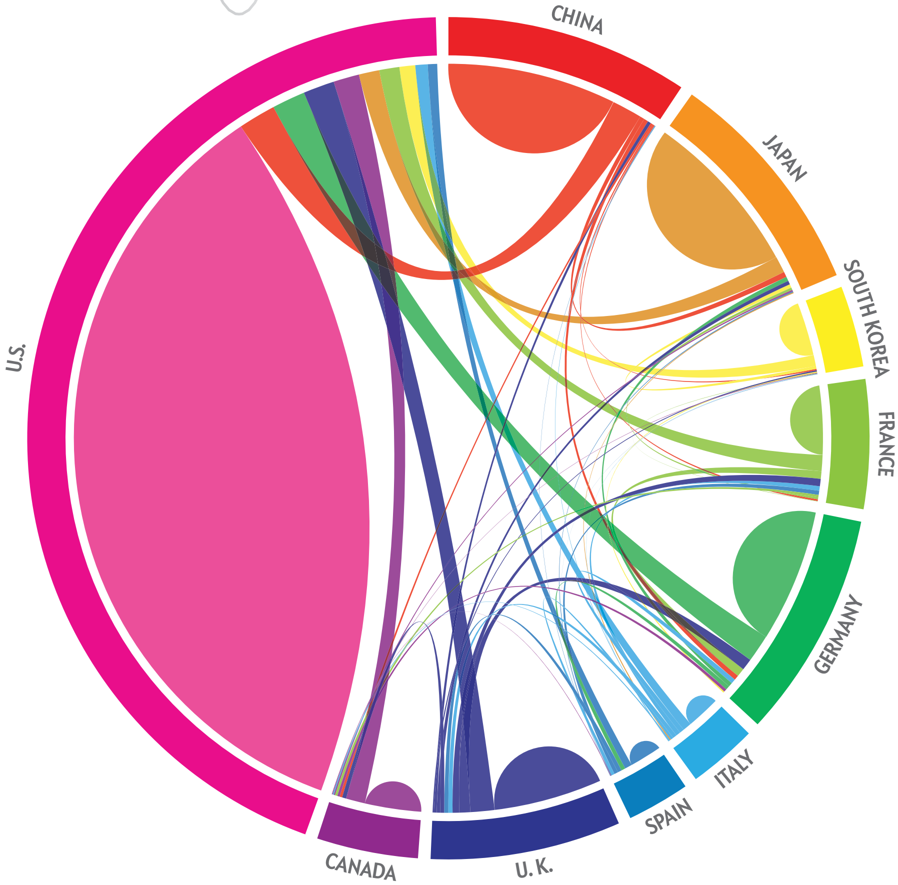
Immigration policies can impede the workings of the new global research. Although communication and collaboration have never been easier, many universities, in particular, find themselves confronting ever more serious immigration-related problems—collaborators unable to obtain visas, graduate students accepted into programs but unable to enter the country because of their nationality. National security is rightly a top priority for the U.S. and other Western countries, but we will need to fine-tune the balance of principles more carefully if we are to participate fully in a world science community.

Even within the community of established research institutions, some troublesome tensions persist or are exacerbated by globalization. And although some of our finest universities are altering their fundamental architecture in response to globalization—Duke University president Richard Brodhead said recently that by the middle of this century the great universities will be "global network universities"—the institutions that have the most experience in operating globally are corporations. The two have increasingly become partners, with corporations funding more and more academic research. This alliance presents challenges that demand the attention of the scientific community.

First, because universities are interested primarily in the advancement of knowledge (in science and other fields), they have been homes to basic research, some of which has led to enormous though unpredictable advances. Because corporations want specific results and products, they are less interested in basic research (the heyday of Bell Labs is behind us). Thus, to the extent research funding is tied to corporate interests, there will be a lamentable diminution in funding for basic research. Second, corporate funding, we have learned, can be tied (by implication) to specific outcomes. For instance, drug companies have manipulated research in ways that have led to questionable science supporting questionable claims of a drug's efficacy.

This is not to say there should be *no* science with corporate funding. Yet a global corporation, itself operating beyond sovereignty, can be powerful, and we must remind ourselves that the master of science is knowledge. And we must strengthen structures and processes designed to protect the advancement of science.

The blossoming of collaborative research is a good thing, not least because it has encouraged more governments—Western and (increasingly) Eastern—to devote major resources to scientific research. The incentives to participate in multinational teams, however, may fade unless we address some basic problems. For instance, can a scientist be funded for the same or related projects by two different sovereign states? If so, can they be any



WITHIN: **Plot includes internal collaborations in the 10 nations with the highest science output. U.S. researchers work with one another more than with outsiders.**

two or only political allies? Currently, as many universities become eligible for significant scientific funding from sovereigns in the Middle East or Asia, the rules governing grants from the U.S. government (especially the rules in the area of "deemed exports") make many of these multifunded projects difficult if not impossible. Are restrictive policies good for science? Will they, in the long run, tend to isolate American scientists if applied strictly? For that matter, who owns the intellectual property produced by multinational teams, especially ones that are funded by more than one sovereign? Is this simply a matter of a contract between the participating bodies, or do the governments, by virtue of funding part (perhaps an undifferentiable part) of the project, have a claim?

U.S. institutions, in particular, are very conscious of research funding statistics as a benchmark for judging the quality of research. Will only funding that comes from U.S. sources continue to count in those rankings?

As the forces of globalization define the trajectory of scientific inquiry for the century, these overarching issues will determine the role and value of science in our lives. Will scientific research be open to all or an opportunity only for the privileged? Will research focus on worldwide needs or narrow interests? Will the scientific community accept disruptive ideas or rely on conventional wisdom? Will countries remain wedded to outmoded rules or be flexible enough to permit deep collaborations on research?

Access to the worldwide discussion about science has never been greater, making participation and advancement a meritocratic exercise. The constantly changing conversations provide unprecedented opportunities to learn, to question assumptions and to break down the walls between disciplines and fields. Yet our trajectory is never inevitably upward. We must take care to make it so.

There is a reason that the Renaissance resulted in so many of the discoveries that still shape our lives. The city-states were idea capitals that brought together the best minds of the time, thus creating communities of individuals who were constantly questioning one another about existing common assumptions. Ultimately the participants became independent enough to be devoted only to the truth. No less than that should be our ideal now.

Which brings us back to Sakharov. Consider this question: Why were so many of the leading Soviet dissidents scientists? One reason is that science created an opportunity for brilliant individuals to excel, despite an environment of deprivation and bureaucratic state control. Scientists, by necessity, because of the nature of their work, had some contact with the international community. And probably most important, scientific inquiry encourages a level of intellectual rigor that would naturally lead one to challenge a broken, despotic system.

Such is case with Alaa Al Aswany, an acclaimed Egyptian novelist who was one of the chief critics of the deposed Mubarak regime. In between his writing and speaking about Egypt's future, he is a working dentist, with an advanced degree from the University of Illinois. As the *New York Times* recounted in a 2008 profile of him, "His three years studying for a master's degree in dentistry in the United States was the most important period in his life. He admits that he had a caricature vision of America, but his travels and discoveries—of, among other things, a gay church and a black pride organization—convinced him that there was more to the United States than what he calls its 'imperialism' in the Arab World."

Aside from the benefits of all the discoveries resulting from globalized science, the spread of scientific research and training will become part and parcel of the opening up and intermingling of societies around the world. No country will be able to forgo the benefits of science, and as they train young people at universities, they will be creating a class that thinks globally, demands responsive institutions and prospers despite local impediments. These new leaders, in the tradition of Sakharov, will be the vanguard of the next stage of globalization. SA

SOURCES: DIGITAL SCIENCE; MARTIN SZOMSZOR *Digital Science*

Stefan Theil is a journalist based in Berlin. He is the former European economics editor at *Newsweek*.

WHY GERMANY STILL MAKES THINGS

Germany has developed a flexible and effective way of moving its best ideas from the university labs to the factory floor

By Stefan Theil

FELIX MICHL AND PHILIPP STAHL HUDDLE OVER A GLEAMING NEW three-armed robot in the sprawling laboratory at the Technical University of Munich (TUM). The robot picks up tiny patches of carbon fiber, each less than a tenth of a millimeter thick but containing 24,000 filaments, and quickly assembles them into a triangular shape. The trickiest task, the investigators say, is to write the software that translates a 3-D computer model of any part—in this case a bicycle seat, but it could also be a medical prosthesis or an automobile component—into instructions for the robot's intricate movements, including the exact position at which the fibers will have their maximum strength and durability. When the project is completed, Michl will use it in his Ph.D. thesis, and Stahl will finish up his undergraduate studies. But the work will get a second life in German factories, including a 70,0000-square-foot, state-of-the-art BMW production facility 30 miles down the road near the medieval town of Landshut, where engineers are crafting the next generation of automobiles.

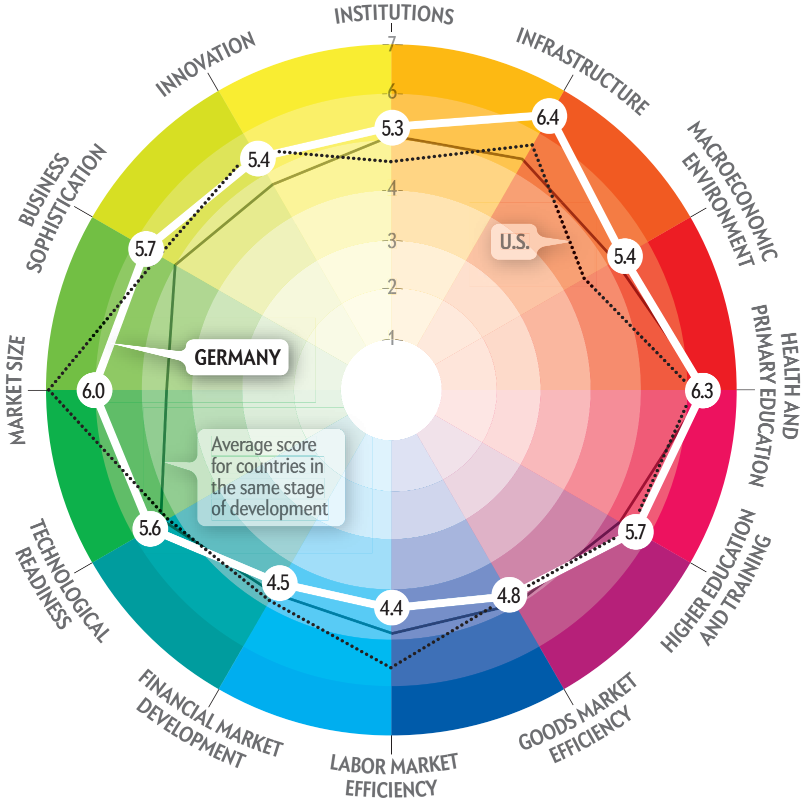
At the moment, the Landshut engineers are focused on the BMW i3, which will be the world's first mass-market, all-electric car made from lightweight components if its 2013 launch comes off as expected. The car's passenger compartment is being built entirely out of carbon composites, which researchers and students such as Michl and Stahl are helping to develop in the Munich labs. The core innovation is a new technology that slashes the production time of complex parts such as the car's side frame to as little as two minutes, making these high-tech composites affordable for mass production for the first time. Three gigantic presses, weighing in at 320 metric tons each, inject resin into the preformed carbon-fiber parts, giving them stiffness. BMW says it has a lead in this composite manufacturing technology over competitors such as Toyota or General Motors. "The knowledge we have in bringing all these elements together isn't something our competitors can easily copy," says BMW project manager Andreas Reinhardt.

That may be. The steady pipeline of innovation that runs from university and government research labs to manufacturers such as BMW is one of the secrets driving the booming German economy. Long belittled as lowly metal bending, German manufacturing sailed through the financial crisis with hardly a dent in profits and employment, even though its workers, among the world's most highly paid, make 10 times what their Chinese counterparts earn. German exports have held their share of the global market against China and other emerging countries, even as the U.S. share has plummeted. Rising industrial employment is one reason Germany, as of May, had a jobless rate of only 5.6 percent compared with America's 8.2 percent, according to the Organization for Economic Co-operation and Development. German manufacturers have stayed glob-

ally competitive because their products—like the BMW i3—are chock-full of science and innovation.

One major factor for Germany's success is that it has managed to tap homegrown scientific research and expertise to move up the technological ladder, concentrating on innovative products and processes not easily copied or undercut by cheaper wages. The textile industry is a case in point. Like America, Germany long ago lost the bulk of its clothing and fabrics manufacturing to cheaper locales such as China, India and Turkey. Still, German companies kept a commanding share of the global market for the ever more complex machines that weave, braid and knit textiles, riding the investment boom in low-wage countries. Meanwhile many of Germany's former textile makers also went high-tech, shifting their specialty to industrial textiles for the automotive and aerospace sectors. Today the national textile industry is at the forefront of composites research, cooperating with universities and government tech centers to develop the precision machinery that braids the carbon fibers into strands—not unlike wool or cotton, except on a microscopic scale. Had Germany given up this industry, it would lack the basis for producing those next-generation composites now being developed at TUM and other labs.

The key for getting this research out of the lab and into the marketplace is the close partnership between research at the universities and today's high-tech factory floors. Most German manufacturers have rich budgets for research, which they often buy from others. Unlike many American firms that might fund a professorship or make a general donation to a university department, German companies usually approach universities with very specific problems they want solved. At TUM, for example, the composites department is funded by SGL Carbon, a German maker of carbon fibers that wants to know what



STANDING OUT: In the Global Competitiveness Index, Germany scores higher than the U.S. on several measures, including the quality of its institutions and infrastructure. See details on the scoring in the report listed in More to Explore.

SOURCE: "THE GLOBAL COMPETITIVENESS REPORT 2011–2012," EDITED BY KLAUS SCHWAB. WORLD ECONOMIC FORUM, 2011

kinds of materials are best suited for the next generation of manufacturing processes. BMW has about a dozen of the department's Ph.D. students on its payroll; their dissertation projects are part of preproduction research for the i3. Equipment makers such as KUKA (robots) and Manz (composites presses) are deeply integrated into the university's research as well.

Multiply this intense networking by dozens of universities specializing in technology and engineering. At RWTH Aachen University, more than 20 university institutes focus on state-of-the-art production techniques, cooperating with machinery makers, robot companies and software developers to make manufacturing processes so efficient that a high-wage country such as Germany can compete with the likes of China. RWTH Aachen is now building a $2.5-billion industrial park for companies partnering in this research. The Karlsruhe Institute of Technology specializes in nanotechnology and materials science, working with Germany's leading chemicals companies, such as BASF, to design new substances that will allow batteries to store renewable energy more efficiently and cheaply. At the Technical University of Dresden, researchers partnering with chipmakers and infotech companies are developing integrated circuits that use one hundredth the energy of current-generation electronics.

The German government, too, plays a crucial role. Whereas the country funds excellent labs for basic science, such as the Max Planck network of 80 institutes covering disciplines as disparate as particle physics and evolutionary biology, Ger-

IN BRIEF

Germany owes its robust economy of recent years in part to the success of its manufacturing sector, from basic materials to tools on the factory floor.

The reason Germany has remained competitive against cheaper manufacturers in Asia and elsewhere is that it has made good use of new technology.

The Fraunhofer network of technical institutes is an example of how researchers and manufacturers work closely together in industry.

The Germans have excelled in old industries such as automobiles and are building centers of excellence in biotechnology and other emerging areas.

Graphic by Arno Ghelfi

many's most economically successful research institution is the Fraunhofer Society. Its network of 60 technology centers is cofinanced by the government and businesses and thus is strictly market-driven. Fraunhofer's $2.5-billion annual budget is also flush with patent income, most notably from its invention of the MP3 data format in the 1980s.

A UNIQUE TRUST

CLOSELY PARTNERING with nearby universities, each Fraunhofer center acts as a transmission belt to an entire cluster of companies networked with the center—and with one another—through collaborative research designed to find its way into processes and products. There are centers for every conceivable industrial sector, including polymer research for chemical companies, precision optics for the makers of sensors and lasers, and nanoelectronics to produce next-generation IT components.

Several centers, such as the Fraunhofer Institute for Production Technology in Aachen, focus on developing cost-efficient manufacturing techniques to keep Germany competitive with China. And for composites research, there is a Fraunhofer project group in Augsburg near Munich that grew out of a cold war–era rocket propulsion lab. Partnering with TUM and more than 50 companies, including BMW, Audi and Airbus owner EADS, the Augsburg center is already working toward the next generation of composite fibers derived not from petroleum but from lignin, an inexhaustible by-product of the wood and paper industries.

What also speeds up the transmission of these technologies is the encouragement of job-hopping of researchers and engineers. The average Fraunhofer scientist, for example, switches to an industrial company after five to 10 years, and many of the best corporate engineers also do stints as professors or Fraunhofer directors. Klaus Drechsler, professor and head of the Institute for Carbon Composites at TUM, spent part of his career at EADS developing composites for the Airbus. Now he is in charge of setting up the new Fraunhofer center for composites in Augsburg. This kind of job-hopping, crucial in diffusing expertise and technology, is much rarer in the U.S., where a government researcher usually stays in one place for life.

This intense and complex collaboration is typical of German innovation. Much of it grew over decades among companies large and small that are now so used to working together they know instinctively what information they can share and what is best kept proprietary. "This trust between companies and institutions that cooperate but also compete is unique—you don't see that in very many countries," says Beñat Bilbao, an economist at the World Economic Forum in Geneva and co-author of the latest "Global Competitiveness Report," which every year shows Germany outranking the U.S. in industrial innovation. Most of these clusters of companies and their suppliers grew organically over decades (in some cases over centuries, such as the former clockmakers in the Black Forest that are now the world's leading producers of precision surgical instruments), which makes them not so easy to copy.

Still, the Germans manage to keep creating such networks in newly emerging industries. One of the latest is the BioEconomy Cluster near Leipzig, where a network of more than 60 companies and research institutes is developing ways to produce chemicals and plastics from biomass, replacing costly and CO_2-spewing petroleum not just for energy but for other products now refined from oil. When Fraunhofer sets up new tech centers, it identifies companies and institutions that are already strong in their fields instead of trying to create something from scratch. "Our philosophy is to take something that's already working and water it so that it grows," says Fraunhofer Society president Hans-Jörg Bullinger. In setting up the new carbon composites cluster, for example, Fraunhofer identified existing companies and university departments and provided funding, staff and a facility to encourage collaborative research.

The second lesson, Bullinger says, is to commit to the long haul. New Fraunhofer centers have their funding secured indefinitely and are left to themselves, with no evaluation taking place for the first five years beyond the requirement that they raise double their seed money from private companies. The companies, too, are invested for the long term; many of Germany's most innovative and tech-driven manufacturers are family-owned companies that do not worry about quarterly reports. A typical German tech company looks like Trumpf, an almost invisible, family-owned firm that has been a world leader in industrial laser technology for over a generation and now has annual sales of almost $3 billion. Fraunhofer, too, added 3,000 new researchers in the worst phase of the financial crisis. "Many countries have tried to copy us," Bullinger says. "But their efforts fail because they think short term."

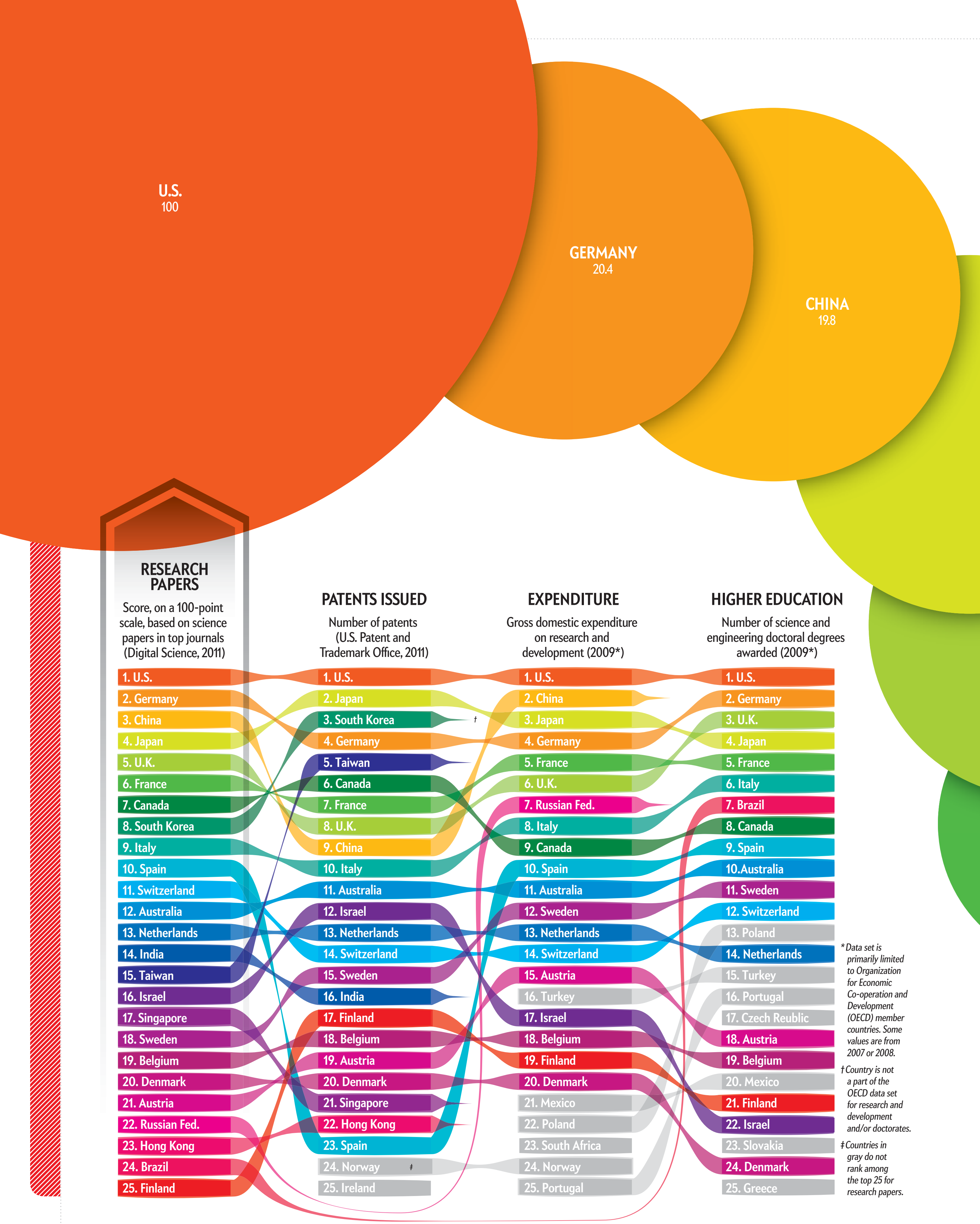
That may be the fatal flaw in President Barack Obama's proposal, unveiled in March, for a $1-billion National Network for Manufacturing Innovation that is explicitly modeled after Germany's Fraunhofer. If Congress approves it, the network will be a public-private partnership in cooperation with manufacturing companies to put in place up to 15 manufacturing technology centers around the country—so far so good. But the funding is only set up for the first four years. In Bullinger's view, that is much too short for the best companies and researchers to commit to serious projects. "The likely result is a scramble for project money instead of something sustainable," Bullinger says. Still, he says, it is a step in the right direction.

The German system has its weak sides, of course. The country's precision culture can be better at perfecting existing technologies than inspiring radical innovation. And the nation has had its periods of "technophobia," during which politicians and protest movements chase away promising high-tech industries, such as biotech in the 1980s. But Germany's drive for industrial innovation has put to rest the old cliché that manufacturing is low tech and has set an example of how to go head-to-head with China. Those graduate students reinventing manufacturing in a university lab in Munich are a model to learn from. SA

MORE TO EXPLORE

The Global Competitiveness Report 2011–2012. Edited by Klaus Schwab. World Economic Forum, 2011. **http://reports.weforum.org/global-competitiveness-2011-2012**

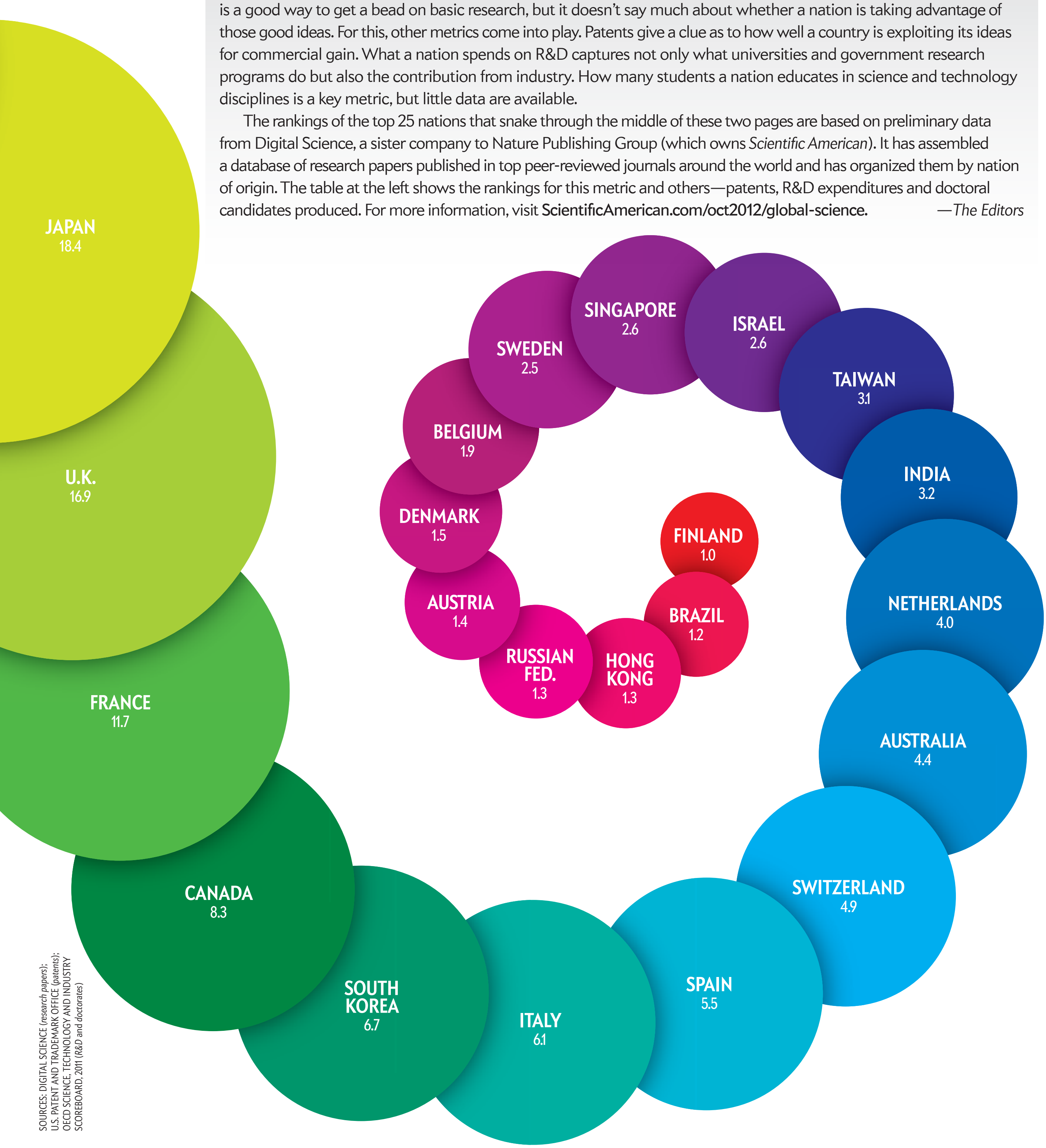
SCIENTIFIC AMERICAN ONLINE
See more information about competitiveness and scientific research at **ScientificAmerican.com/oct2012/global-science**


U.S.
100
GERMANY
20.4
CHINA
19.8
RESEARCH PAPERS
Score, on a 100-point scale, based on science papers in top journals (Digital Science, 2011)
1. U.S.
2. Germany
3. China
4. Japan
5. U.K.
6. France
7. Canada
8. South Korea
9. Italy
10. Spain
11. Switzerland
12. Australia
13. Netherlands
14. India
15. Taiwan
16. Israel
17. Singapore
18. Sweden
19. Belgium
20. Denmark
21. Austria
22. Russian Fed.
23. Hong Kong
24. Brazil
25. Finland
PATENTS ISSUED
Number of patents (U.S. Patent and Trademark Office, 2011)
1. U.S.
2. Japan
3. South Korea
†
4. Germany
5. Taiwan
6. Canada
7. France
8. U.K.
9. China
10. Italy
11. Australia
12. Israel
13. Netherlands
14. Switzerland
15. Sweden
16. India
17. Finland
18. Belgium
19. Austria
20. Denmark
21. Singapore
22. Hong Kong
23. Spain
24. Norway
‡
25. Ireland
EXPENDITURE
Gross domestic expenditure on research and development (2009*)
1. U.S.
2. China
3. Japan
4. Germany
5. France
6. U.K.
7. Russian Fed.
8. Italy
9. Canada
10. Spain
11. Australia
12. Sweden
13. Netherlands
14. Switzerland
15. Austria
16. Turkey
17. Israel
18. Belgium
19. Finland
20. Denmark
21. Mexico
22. Poland
23. South Africa
24. Norway
25. Portugal
HIGHER EDUCATION
Number of science and engineering doctoral degrees awarded (2009*)
1. U.S.
2. Germany
3. U.K.
4. Japan
5. France
6. Italy
7. Brazil
8. Canada
9. Spain
10.Australia
11. Sweden
12. Switzerland
13. Poland
14. Netherlands
15. Turkey
16. Portugal
17. Czech Reublic
18. Austria
19. Belgium
20. Mexico
21. Finland
22. Israel
23. Slovakia
24. Denmark
25. Greece
*Data set is primarily limited to Organization for Economic Co-operation and Development (OECD) member countries. Some values are from 2007 or 2008.
†Country is not a part of the OECD data set for research and development and/or doctorates.
‡Countries in gray do not rank among the top 25 for research papers.

The World's Best Countries in Science

What makes one country better than another in science? It's not an easy thing to measure. Publishing research papers is a good way to get a bead on basic research, but it doesn't say much about whether a nation is taking advantage of those good ideas. For this, other metrics come into play. Patents give a clue as to how well a country is exploiting its ideas for commercial gain. What a nation spends on R&D captures not only what universities and government research programs do but also the contribution from industry. How many students a nation educates in science and technology disciplines is a key metric, but little data are available.

The rankings of the top 25 nations that snake through the middle of these two pages are based on preliminary data from Digital Science, a sister company to Nature Publishing Group (which owns *Scientific American*). It has assembled a database of research papers published in top peer-reviewed journals around the world and has organized them by nation of origin. The table at the left shows the rankings for this metric and others—patents, R&D expenditures and doctoral candidates produced. For more information, visit **ScientificAmerican.com/oct2012/global-science.** —*The Editors*



SOURCES: DIGITAL SCIENCE (*research papers*); U.S. PATENT AND TRADEMARK OFFICE (*patents*); OECD SCIENCE, TECHNOLOGY AND INDUSTRY SCOREBOARD, 2011 (*R&D and doctorates*)

Graphic by Arno Ghelfi

Philip G. Altbach is J. Donald Monan, S.J. University Professor and director of the Center for International Higher Education at Boston College.

Qi Wang is assistant professor at the Graduate School of Education at Shanghai Jiao Tong University in China.

CAN CHINA KEEP RISING?

World-class status for research excellence comes with a new set of challenges

By Philip G. Altbach and Qi Wang

FOR TWO DECADES NOW CHINA HAS BEEN ASIA'S JUGGERNAUT. It builds whole cities from scratch, leads the world in energy construction and has grown its economy by nearly 10 percent a year. Breakneck growth has not been confined to the economy—China has also become a scientific research world power in a remarkably short time.

The mainland's universities have undergone a dramatic expansion. In 1978 China had only 860,000 students in higher education—a mere 1.6 percent of school-age adults. That figure ballooned to more than 23 million students, or about 27 percent, by 2011. This growth has made the nation's academic system number one in the world in terms of student enrollments. China now has more than 100 research universities in all fields, many of them with an emphasis on science and engineering. Graduate student enrollments have also escalated from 280,000 in 2000 to 1.6 million in 2011.

China's leaders recognize that scientific research and higher education are essential to attaining global leadership. Despite its impressive achievements, however, the path to academic excellence and world-class status is by no means assured. For 40 years China has tried to rapidly expand its overall research and education system while instilling excellence in a handful of centers. So far China has juggled these two goals by starving the bottom to feed the top. A yawning gulf exists between elite institutions such as Peking University and Tsinghua University and institutions catering to mass enrollments. The top few percent of Chinese graduates have world-class educations, but many who earn degrees are not well trained and cannot find jobs.

As much as China has accomplished, making significant improvements is going to be tough. The nation's leaders will find over the next decade that simply pumping more resources into the elite research universities will not achieve true world-class status for the academic system. They are also going to have to preside over significant changes in academic culture, administration and leadership. Further progress will involve changes in how universities function and in how the culture of academe is perceived in China.

ENGINES OF EXCELLENCE

BEFORE THE COUNTRY opened up in the late 1970s, China's science and technology system employed a Soviet model: specialized institutions conducted research, and narrowly focused universities delivered education and training. This model failed because research was separate from teaching, interdisciplinary work was impossible, resources were scarce, and tight political controls and ideology were paramount. The Cultural Revolution from 1966 to 1976 closed all of higher education for a decade and destroyed much of what had been built previously. In the 1990s China expanded and restructured higher education to meet its economic ambitions.

The government soon realized, however, that the country performed poorly in knowledge creation and innovation according to various global competitiveness reports and rankings. In 1995 China started Project 211 to develop 100 universities

IN BRIEF

China's economy has been growing quickly, and so has its research efforts. In a short time, it has become a world leader—a startling achievement.

The Chinese Academy of Sciences is on a par with some of the best scientific research institutions.

This rapid rise in research prowess has been concentrated largely at the top, however. Currently a yawning gulf exists between the elite institutions and most of the others.

China's universities will have to overcome a host of problems, such as inconsistent standards and academic culture, to continue improving.

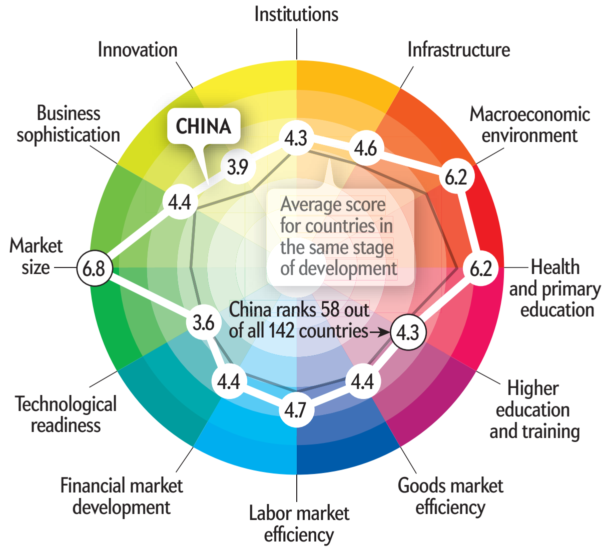
and several key scientific disciplines by the early 21st century. Three years later it launched Project 985, which has come to focus on 39 key research universities of excellence. The national and local governments and a few universities invested about $15 billion in additional funding to these select institutions.

These efforts have provided significant resources for a small number of Chinese universities and enhanced capacity for scientific and technological research and innovation. With special-funding support from a few national projects, the universities have managed to attract elite researchers and academics from abroad, mainly from the Chinese diaspora, to work in China. Leading research universities' budgets are coming close to the level of their peers in other parts of the world. In terms of research papers, output has increased to a level close to that of American universities. In 2008 the Project 985 universities produced 6,073 patents (both domestic and international), compared with only 346 in 1999. According to the U.S. Patent and Trademark Office, the number of Chinese patents registered in the U.S. increased from 41 in 1992 to 1,874 in 2008.

SYSTEMIC CHALLENGES

AN EMERGING private (*minban*) sector largely serves the bottom of the system. Quality is poor—and the education is mainly vocational—in fields such as information technology and business studies. Whereas some of the better private institutions produce competent midlevel workers, many of the graduates lack usable skills for China's development in the global knowledge economy. A few such institutions offer undergraduate degree programs. Students who are least able to afford high tuitions are awarded degrees of questionable value or pay a relative fortune for low-quality and low-prestige vocational preparation.

The core of China's quality problem involves the system's professors. Nationally, one third of academic staffers hold only a bachelor's degree (the proportion reaches 60 percent in the new private sector), which indicates that the skill level of many of the faculty members is rather low. The number of academic staffers with a doctorate, in both public and private institutions, has increased recently but still constitutes only 14 percent of professors, compared with 70 percent of faculty at reputable Chinese institutions who have earned a doctorate. Academic salaries are low, with the exception of a small percentage of highly productive academics at top universities. Chinese academics do not typically earn enough to support a middle-class lifestyle and must moonlight. In a recent study of academic salaries in 28 countries that included Brazil, Russia and India, China scored among the lowest when it was measured by purchasing-power parity.



POTENTIAL: China's huge market size makes it stand out from the pack in the Global Competitiveness Index.

SOURCE: "THE GLOBAL COMPETITIVENESS REPORT 2011–2012," EDITED BY KLAUS SCHWAB. WORLD ECONOMIC FORUM, 2011

This environment is not good enough to sustain a world-class academic culture. Effective universities need a commitment to basic research that is not closely linked to monetary gain. They must encourage interdisciplinary work, accommodate shared governance and establish clearly understood norms. Professors need academic freedom, access to all sources of information and analysis, and the latitude to publish their work. The university in all its functions must be both meritocratic and reasonably transparent, which means that personal, political and institutional connections must not influence decisions regarding personnel, research or other academic matters.

These things are generally taken for granted in the developed world, but in Chinese universities they remain a challenge. Even the prestigious universities worry that their curricula and teaching methods are outdated and inappropriate for the modern world and encourage rote learning at the expense of creativity and critical thinking. The Chinese government, which has centralized administrative power over academic resources and scholarships, may restrict the growth of young scholars and disrupt the fairness of competition for research excellence. The academic environment is also known to be rife with plagiarism, cheating on examinations and other elements of corruption. There is considerable use of *guanxi* (personal connections and networks) as well. Faculty culture is often hierarchical and bureaucratic.

Many of the leading universities are considering an innovative liberal arts–oriented undergraduate curriculum and are beginning to focus on teaching methods that encourage students to be more active. They are also increasingly hiring young academics with Ph.D.'s from the best overseas universities and introducing more rigorous internal evaluation. Yet changing the academic culture in the bottom 80 percent or more of the academic system is going to be especially difficult. Those institutions remain quite traditional and bureaucratic. Poor practices tend to be ingrained in the system and difficult to change. So far a combination of resources and a will to reform, at least at the top of the academic system, has served China well. Cultural change may come eventually, but it will come slowly. SA

MORE TO EXPLORE

Leadership for World-Class Universities: Challenges for Developing Countries. Edited by Philip G. Altbach. Routledge, 2010.

The Road to Academic Excellence: The Making of World-Class Research Universities. Edited by Philip G. Altbach and Jamil Salmi. World Bank, 2011.

SCIENTIFIC AMERICAN ONLINE
For more on China's institutions, see ScientificAmerican.com/oct2012/global-science

Graphic by Arno Ghelfi

Michael M. Crow is president of Arizona State University.

CITIZEN SCIENCE U.

The best way to teach today's hyperconnected students is to get rid of the departments of geology and biology

By Michael M. Crow

EVERY SO OFTEN LEADERS FROM BUSINESS, INDUSTRY AND GOVernment sound the alarms about the waning of U.S. scientific and technological prowess and call on academe to produce more graduates. Education leaders at the university level then point an accusatory finger at primary and secondary schools for producing marginal students and at the students themselves for having little interest in science. Yet responsibility rests largely with the universities. They, after all, educated the teachers—the same teachers who seem to have made learning math and science too much like an Olympic triathlon: an ordeal from which few stars emerge.

The prevailing approach to teaching *s*cience, *t*echnology, *e*ngineering or *m*athematics, or STEM, generally serves only to enhance gifted students already predisposed toward science and math. These elite students may hearten their professors, but the other 90 percent are being shortchanged. Science and math are foundational subjects of the liberal arts and also align with the increasingly rigorous demands of the contemporary labor market. Yet when average students confront the university's ossified approaches to these crucial subjects, they flee in vast numbers. It is no wonder math performance has declined at all levels of our society, including hundreds of thousands of teachers who find themselves ill equipped to inspire excitement in these areas to the levels necessary for our national competitiveness in the global economy.

Too many average students now avoid STEM courses except for the few that are required for graduation. Figuring out how to help them overcome the culturally fatal fear of science Carl Sagan warned of—specifically how to attract and retain them in STEM programs at the university level—is key to improving STEM skills and critical thinking in the population at large.

Young people entering universities today are hyperconnected, multitasking visual learners. They grew up with ubiquitous information technologies that offer access to unlimited information. Steeped in an information culture, these students are apparently less willing to ponder algorithms about combinatorial optimization or the entropy of a monatomic ideal gas without some additional context or understanding of purpose. Standardized sequential instruction will always be at odds with their nonlinear multitasking approaches to learning. The new technologies can, however, when appropriately channeled, help students rapidly integrate and master broad knowledge from complex and interrelated scientific disciplines.

To be fair, one reason students have been defecting from science and technology is that our economy has shifted toward a service sector dominated by the verbal and the visual. But another root

IN BRIEF

Responsibility for the state of science literacy rests largely with institutions of higher education, who are the ones that educate the teachers.

In STEM, universities are failing the majority of students, in part because adherence to rigid academic approaches makes these fields forbidding.

Arizona State University eliminated some academic departments such as biology and geology and embraced a "transdisciplinary" approach.

In the past decade undergraduate enrollments in STEM majors at Arizona State have doubled overall and increased significantly for women and minorities.

cause is a denial among those in academe that our incoming students are fundamentally different than those of previous decades. The trouble is that most professors were trained to think in terms of biology, chemistry and other rigid academic disciplines. This model of higher education has failed to inspire the last two generations of students.

That is why we have revised the STEM enterprise at Arizona State University over the past decade, as part of a broader reconceptualization of the entire university. Our goal was to find a way of providing the best possible education for the students of Arizona and to develop a new paradigm for the American research university. As the nation's youngest major research institution, Arizona State has the advantage of not being hidebound by tradition, which has freed us to develop an egalitarian institution committed to academic excellence, inclusiveness to a broad demographic and maximum societal impact. We call this model the "New American University."

To spur creativity and innovation, we introduced a set of "design aspirations"—eight interrelated principles that embrace such goals as transforming society, emphasizing transdisciplinary approaches, pursuing research for its potential usefulness and encouraging creative risk taking.

When we began our STEM efforts a decade ago, our goal was to double the number of majors as quickly as possible and, more broadly, to produce students with a new spirit of engagement in scientific and technological futures. To accomplish our objectives in this context, we offered our faculty the opportunity to design teaching, learning and discovery platforms in STEM areas. To liberate their thinking, we specified no limits whatsoever regarding philosophical or pedagogical boundaries.

In recent years we have reconfigured scores of academic units into new entities, including more than a dozen transdisciplinary schools, which arose from merged and restructured traditional academic departments. In the process, we have eliminated a number of departments—among them anthropology, geology, sociology and several areas of biology—that had outlived their usefulness.

The School of Earth and Space Exploration, for example, combines science and engineering research and education to advance our understanding of our planet and the universe. The school brings transdisciplinary fluidity to the former programs in geology and astronomy, fostering collaboration among earth and planetary scientists, astronomers, astrophysicists and cosmologists. Affiliated engineers bring technological expertise that advances the development and deployment of critical scientific instrumentation on planet Earth and in space. The theme of exploration represents our quest to discover the origins of the universe and to expand our understanding of space, matter and time.

WE HAVE SEEN A ROBUST EXPANSION IN THE NUMBER OF GRADUATES IN CORE DISCIPLINES SUCH AS PHYSICS AND CHEMISTRY.

The School of Human Evolution and Social Change combines faculty from the former departments of anthropology and sociology, thus giving students an integrated curriculum in the social, behavioral and natural sciences focused on the evolution of our species and trajectories of human societies. Unlike traditional academic departments, the professors and graduate students are free to organize themselves to best tackle critical global problems.

These transdisciplinary departments complement our large-scale research initiatives, such as the Biodesign Institute and the Global Institute of Sustainability, the latter of which incorporates the first-of-its-kind School of Sustainability.

To broaden the reach of our engineering programs, we offer students two separate approaches—theoretical and practical. The Ira A. Fulton Schools of Engineering are organized into five research-intensive divisions, including the School of Biological and Health Systems Engineering; the School of Computing, Informatics and Decision Systems Engineering; and the School of Sustainable Engineering and the Built Environment. On the other hand, the College of Technology and Innovation at our Polytechnic campus focuses on use-inspired translational research and offers students interested in direct entry into the workforce an experiential learning environment. These "differentiated learning platforms" offer students with varying levels of preparation access to excellence in cutting-edge STEM education.

The results have been encouraging. We have seen a robust expansion in the number and diversity of graduates in traditional core disciplines such as physics and chemistry. Through innovation and linkages with other fields, quantitative literacy throughout the university has improved significantly as measured by learning assessments. In the life sciences alone, enrollment is about 4,600 students, up from 1,675 in 2001. We have 10,000 or so students studying engineering and technology, up from less than 5,000 10 years ago. Undergraduate enrollment in all STEM areas has increased to approximately 16,000, doubling the number over the past decade. The enrollment of women in STEM majors has nearly doubled, and the enrollment of minority students has increased by 141 percent.

Efforts to advance STEM education should remind us that reconceiving how science and technology are organized into academic disciplines has the potential to profoundly affect learning outcomes. It is incumbent on our academic community to pursue transdisciplinary teaching, research and creative excellence focused on the major challenges of our time. SA

MORE TO EXPLORE

New American University: http://newamericanuniversity.asu.edu

SCIENTIFIC AMERICAN ONLINE
For more on research universities, go to ScientificAmerican.com/oct2012/global-science

Paula Stephan is a professor of economics at Georgia State University and a research associate at the National Bureau of Economic Research. She is author of *How Economics Shapes Science* (Harvard University Press, 2012).

THE OTHER 1 PERCENT

Income inequality is rife in the world of U.S. science—and it's for the better

By Paula Stephan

THE U.S. HAS LONG ENJOYED A PREEMINENT POSITION IN the world of science. The nation does more research, publishes more articles that are cited by more scientists and wins more Nobel Prizes than any other. It has also long been the chief destination for scientists and engineers from other countries—many U.S. Nobel laureates are foreign-born.

What explains the strong productivity of the U.S. workforce, and what makes the U.S. so attractive to the foreign-born and foreign-educated? A big part of the answer is resources: the U.S. has a strong history of supporting research at universities—the country devotes more than 0.3 percent of its GDP to it every year. A study of academic careers by country found that faculty members in the U.S. earn higher salaries than anywhere in Europe, save perhaps Ireland (before the 2008 crash). Full professors in France or Germany earn about €4,500 a month, 55 percent of what their U.S. counterparts earn. Although the job market for Ph.D.'s has been tight recently, there is no reason to think that the U.S. is still not ahead on pay level.

But high pay is only part of what puts the U.S. out in front. Unequal pay among researchers contributes significantly to a nation's success in attracting the best and the brightest. Universities in the U.S. have greater leeway than those in most other places to reward performance and to pay high salaries to attract star researchers.

Pay inequality is not the norm abroad. Many countries tie salary to rank and years of experience, which means that everyone with the same amount of experience at the same rank earns precisely the same amount. The only reward for those who are more productive is the possibility of being promoted more quickly or, in some countries, being allocated more resources for research. Even promotion, however, can be accompanied by a negligible increase in salary. In Norway, for example, a full professor earns at best about 30 percent more than someone who is just starting his or her career. In the U.S., a full professor earns, on average, 60 to 80 percent more than someone just starting out, but exceptionally productive full professors earn four to five times more than what a new hire makes. Japan follows a model that is closer to that of the U.S. than that of Europe in terms of relative pay, rewarding full professors at close to twice the compensation of entry-level faculty.

In Europe, a scientist is less apt to move from one job to another once he or she is hired by a university. There is little incentive to move. Faculty in most of Europe are civil servants and receive the same salary regardless of where they work. Salary plays no role in recruiting faculty from one institution to another within a country.

In the U.S., in contrast, substantial variation exists in three key dimensions of salary across universities: starting salary, salary paid within rank, and salary differentials across rank. For example, the

IN BRIEF

The U.S. leads the world in science by almost any measure. The resources devoted to university research have a lot to do with this success.

But the ability to reward high productivity with high pay is key to the success of U.S. research centers in attracting and retaining the best talent.

Europe, in contrast, treats its professors as civil servants, with pay awarded on the basis of years of experience rather than productivity.

Saudi Arabian schools are trying to jump-start their reputations by lavishing high salaries on visiting scientists, with mixed success.

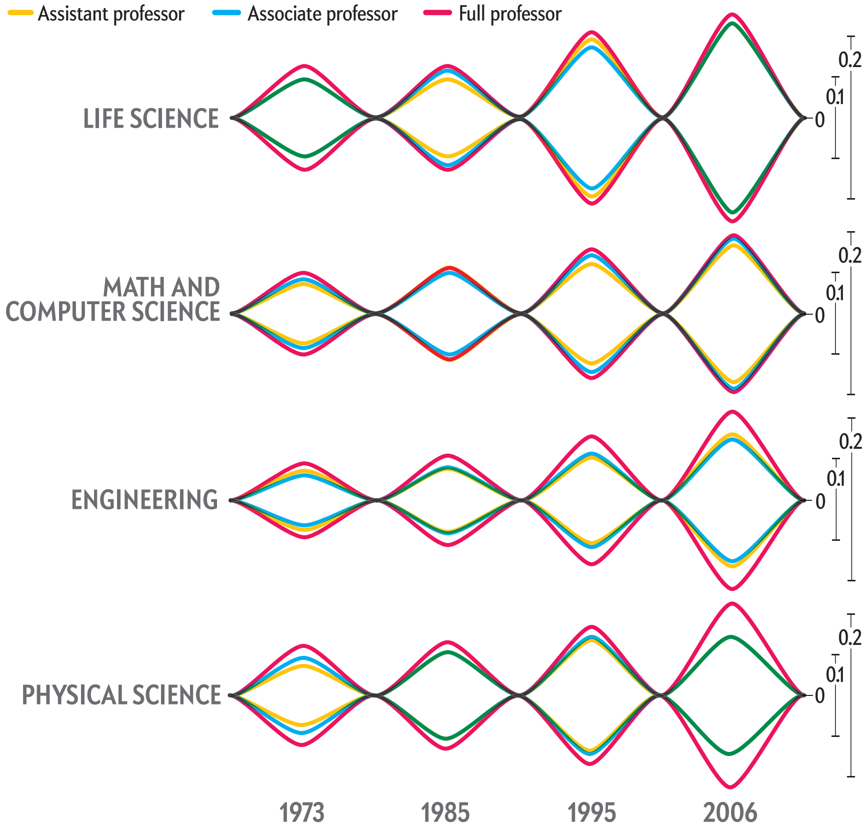
starting average salary for faculty in computer and information sciences in 2008 at public institutions was just shy of $85,000. The highest starting salary reported that year was slightly more than $125,000. Among associate professors, the spread was even greater: mean salary was $100,000, and the highest was almost twice that ($193,000). For full professors—the top academic rank—the mean was $133,000, and the highest was $301,000.

Productivity is a major factor contributing to the pay differentials. Most U.S. universities take into account research productivity, measured by the quality of papers published, in considering salary raises and promotions. Yet productive scientists are also often recruited away to higher-paying institutions—which tend to be private. Indeed, in 2010 only one public institution (the University of California, Los Angeles) paid a top-20 salary—and that was $43,000 less than high-paying Harvard University. Private institutions not only pay more; they generally can provide better facilities and attract better students for faculty members to work with.

One way to measure salary differentials among persons of the same rank is to compute the "Gini" coefficient. In countries where everyone gets the same salary at the same rank for comparable years of experience, the Gini coefficient within rank is 0. The most extreme pay differential would be a Gini coefficient of 1—if, say, all faculty members except one were to earn nothing. No pay scale is so extreme, of course, but the Gini coefficient is nowhere near 0 for faculty in the U.S. For assistant professors in engineering, the Gini coefficient is 0.164; for full professors, it is 0.22, indicating considerable inequality in salaries earned among those faculty holding the same rank, as well as increasing inequality as one moves from lower ranks to upper ranks. Given the statistics on salary and the considerable spread in salary among teachers of the same rank, it is a pretty safe bet that high salaries and a system that rewards productivity play an important role in the U.S.'s science ranking.

Pay alone is not enough. If it were, King Abdullah University of Science and Technology (KAUST) in Saudi Arabia would probably be near the uppermost tier of any global ranking of universities.

Income Gap within U.S. Faculty Positions
(as represented by the Gini coefficient: 0 equals no inequality; 1 equals maximum inequality)



TRICKLE-UP THEORY: Pay inequality has been rising broadly among faculty in science and engineering, as shown in this plot of Gini coefficients from 1973 to 2006 (from the National Science Foundation's Survey of Doctorate Recipients). In life and computer sciences, pay scales vary widely at all levels of experience; in engineering and physics, pay differentials are especially pronounced among experienced faculty.

SOURCE: SURVEY OF DOCTORATE RECIPIENTS, NATIONAL SCIENCE FOUNDATION, 2011

A 2008 study of faculty pay in 15 representative countries, including the U.K., Germany, the U.S., Japan and China, found that Saudi Arabian senior faculty make the highest salaries, adjusted for cost of living. Yet KAUST is nowhere near the top in research rankings.

The U.S. has long been known for excellent academic institutions that produce strong science. Having the resources to hire and reward highly productive faculty has been key to this success. In recent years, however, pay inequality in the U.S. has increased significantly. Many public institutions have been receiving fewer resources from their states. At the same time, endowments of private institutions such as Harvard and Yale have grown considerably, allowing them to hire aggressively. Whether growing pay inequality is constructive for U.S. universities is a matter of debate.

Scientists care about more than just money. They also value independence and the challenge of doing science. But resources are essential to giving the top scientists free rein to pursue their passions. When it comes to producing the best science possible, it pays to foster a society of elites. SA

MORE TO EXPLORE

International Comparison of Academic Salaries: An Exploratory Study. Laura E. Rumbley et al. Boston College, October 2008.

How Economics Shapes Science. Paula Stephan. Harvard University Press, 2012.

For salary comparisons among academics in different countries, see the European University Institute Web site: **http://eui.eu**

SCIENTIFIC AMERICAN ONLINE
For information on R&D spending, patents and other data, go to **ScientificAmerican.com/oct2012/global-science**

Graphic by Arno Ghelfi

CULTURE OF CREATIVITY

The rise of China and India bodes well for science, says British Royal Society president Paul Nurse

Interview by Fred Guterl

PAUL NURSE KNOWS VISCERALLY WHAT IT TAKES TO BUILD A productive scientist. Raised by his grandparents—a handyman and a cook—in class-conscious England, Nurse went on to do pioneering research in DNA and cell division, for which he won a Nobel Prize in 2001. In 2003 he was named president of the Rockefeller University in New York City, and in 2010 he became president of the British Royal Society, which makes him something of an expert in the cultural differences between European and North American scientists. He splits his time between London and New York, where he still does laboratory research. Nurse talked with SCIENTIFIC AMERICAN about the changing face of global science.

What are the trends that you are seeing?
There is a massive collaboration going on in science. More than 35 percent of articles being published in the highest-quality journals are now internationally collaborative, up from about 25 percent 15 years ago. Collaboration is increasing and probably will increase to a very surprising level.

What does that mean for science?
There are some cultural differences in the way we approach science. In the U.S., for example, there's a particular emphasis on the individual. In Europe, the focus is more on collaboration. In the Far East, there is interest in generating large quantities of data, the bedrock on which science works. This cultural mix is very enriching.

What do you make of the rise of Asia?
We're now seeing a gradual increase in the strength of countries and cultures that are outside what we might call the Western tradition. China's leaders have recognized that science is crucial for the nation's development and for improving the quality of people's lives. So they're making science a priority for their country and trying to make it a profession to which the very best are attracted.

Chinese science has come on fantastically in recent decades. We're seeing incredibly efficient and effective programs set up to generate large quantities of DNA-sequencing data, which are being analyzed by informatics. This is not a trivial thing to deliver in an efficient and effective way. Many who are now working in biomedicine look to China for assistance. They are doing that kind of activity extremely well. But they would probably think even themselves that they need to pay attention to the most innovative science.

India has produced very fine scientists. It hasn't yet invested quite as much as China. India has had a long tradition in certain sciences, particularly in mathematics and physics, and will become increasingly important in coming years.

Is culture important to what kind of science a nation produces?
Certain sciences seem to prosper well in certain cultures. Hungary is good on theory and mathematics, for example—it's difficult to quite know why. The U.K. is good at science despite the fact that we don't invest quite as much as other countries—1.8 percent [of GDP] compared with 2.9 percent for the U.S. Although we only have 1 percent of the population, we're producing 14 percent of the highest-impact papers, which is extraordinary. I do not know why British science is so effective. It may have something to do with

the general culture, with maybe a mix of attention to empiricism as well as theory, a certain practicality, a liberality, an openness to ideas.

What does increasing international collaboration mean for big science?

The symbolism of getting many countries working together in science is great. With big bits of kit—like big [particle] colliders [such as the Large Hadron Collider] or big telescopes—the more international we are, the better. If we can get a bigger telescope into space by working together, let's do it.

When we come to other sciences like the biological sciences, sequencing the human genome, and so on, the pieces of kit are less expensive and [costs] can be spread over more countries. But the key is to get them to talk to one another so that you're not just all doing the same work. Sequencing large amounts of data is frankly not all that interesting to do, and you don't want to be doing it if somebody else is already doing it. When there are different centers that can share data, the sums of the parts can lead to a greater whole.

In genomics, where do you see this collaboration leading?

Data collection will be very important in the coming years. Understanding human genetic variation by, for example, sequencing 1,000 humans with different ethnic backgrounds is a project that is international and across the board and where different centers can contribute. The use of genomics to catalogue all the life-forms on the planet is also taking off. This is simply using genome sequencing to define all the different species of animals, plants, microbes and viruses in the world. Genome sequencing gives it the precision that we need, and it has to be combined with taxonomy and the ecology. Creating an encyclopedia of life is truly collaborative.

What other problems lend themselves to collaboration?

How we can produce energy in a more sustainable, less polluting way will also cross international boundaries, both in terms of where the research is done and how we technically solve the problems, which might involve shifting energy in different ways across national boundaries.

How do immigration policies factor in?

I'm a bit distressed by it. Science thrives on a mixing of different individuals and cultures. Switzerland, which has been open to accomplished immigrants, punches way above its weight in science. Open doors in science absolutely encourage science. The U.S. has at times been very open to immigration and at other times less open to it. In the 20th century the mixture of rigor from middle European immigrants and the ability of the Americans to get things done shifted the U.S. into a prime position in science. Britain was preeminent in science when we had empire and were able to constantly reach out to different cultures.

There can be a problem when the perception from other countries emerges that a particular country isn't open. That keeps people from applying. Also, for countries such as India and China to move into the top drawer, they have to attract individuals from overseas to come work there and have to develop strong interactions with people from overseas.

How will collaboration in science play out on the world stage?

Scientists speak the same language. We understand one another in different countries because we deal with things in similar ways. We take a common approach to problems. Science is a catalyst that can break down the gulf between nations. SA

SCIENTIFIC AMERICAN ONLINE
For more of the conversation with Paul Nurse, go to ScientificAmerican.com/oct2012/paul-nurse

Photograph by John Spinks

Terry Sejnowski is an investigator with the Howard Hughes Medical Institute and is Francis Crick Professor at the Salk Institute for Biological Studies, where he directs the Computational Neurobiology Laboratory.

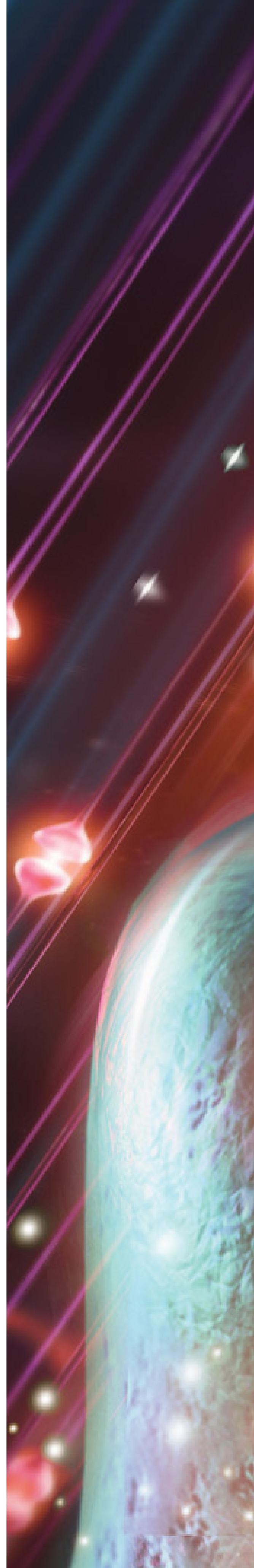
Tobi Delbruck is co-leader of the sensors group at the Institute of Neuroinformatics at the University of Zurich.

NEUROSCIENCE

THE LANGUAGE OF THE BRAIN

The brain makes sense of our experiences by focusing closely on the timing of the impulses that flow through billions of nerve cells

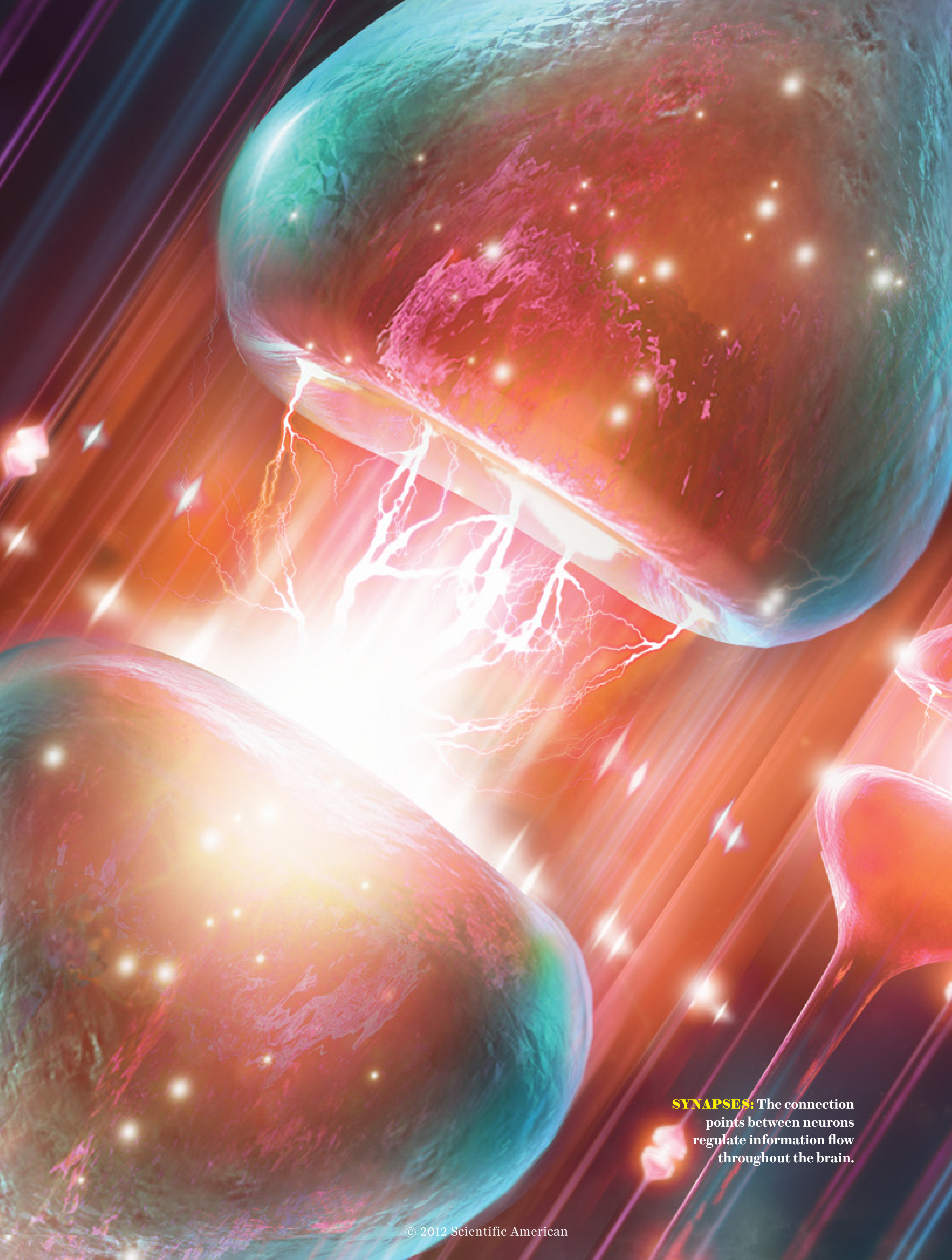
By Terry Sejnowski and Tobi Delbruck



OUR BRAINS ARE BETTER THAN GOOGLE OR THE BEST ROBOT FROM iROBOT.

We can instantly search through a vast wealth of experiences and emotions. We can immediately recognize the face of a parent, spouse, friend or pet, whether in daylight, darkness, from above or sideways—a task that the computer vision system built into the most sophisticated robots can accomplish only haltingly. We can also multitask effortlessly when we extract a handkerchief from a pocket and mop our brow while striking up a conversation with an acquaintance. Yet designing an electronic brain that would allow a robot to perform this simple combination of behaviors remains a distant prospect.

Illustration by Kenn Brown, Mondolithic Studios



SYNAPSES: The connection points between neurons regulate information flow throughout the brain.

How does the brain pull all this off, given that the complexity of the networks inside our skull—trillions of connections among billions of brain cells—rivals that of the Internet? One answer is energy efficiency: when a nerve cell communicates with another, the brain uses just a millionth of the energy that a digital computer expends to perform the equivalent operation. Evolution, in fact, may have played an important role in pushing the three-pound organ toward ever greater energy efficiencies.

Parsimonious energy consumption cannot be the full explanation, though, given that the brain also comes with many built-in limitations. One neuron in the cerebral cortex, for instance, can respond to an input from another neuron by firing an impulse, or a "spike," in thousandths of a second—a snail's pace compared with the transistors that serve as switches in computers, which take billionths of a second to switch on. The reliability of the neuronal network is also low: a signal traveling from one cortical cell to another typically has only a 20 percent possibility of arriving at its ultimate destination and much less of a chance of reaching a distant neuron to which it is not directly connected.

Neuroscientists do not fully understand how the brain manages to extract meaningful information from all the signaling that goes on within it. The two of us and others, however, have recently made exciting progress by focusing new attention on how the brain can efficiently use the timing of spikes to encode information and rapidly solve difficult computational problems. This is because a group of spikes that fire almost at the same moment can carry much more information than can a comparably sized group that activates in an unsynchronized fashion.

Beyond offering insight into the most complex known machine in the universe, further advances in this research could lead to entirely new kinds of computers. Already scientists have built "neuromorphic" electronic circuits that mimic aspects of the brain's signaling network. We can build devices today with a million electronic neurons, and much larger systems are planned. Ultimately investigators should be able to build neuromorphic computers that function much faster than modern computers but require just a fraction of the power [see "Neuromorphic Microchips," by Kwabena Boahen; Scientific American, May 2005].

CELL CHATTER

LIKE MANY OTHER NEUROSCIENTISTS, we often use the visual system as our test bed, in part because its basic wiring diagram is well understood. Timing of signals there and elsewhere in the brain has long been suspected of being a key part of the code that the brain uses to decide whether information passing through the network is meaningful. Yet for many decades these ideas were neglected because timing is only important when compared between different parts of the brain, and it was hard to measure activity of more than one neuron at a time. Recently, however, the practical development of computer models of the nervous system and new results from experimental and theoretical neuroscience have spurred interest in timing as a way to better understand how neurons talk to one another.

Brain cells receive all kinds of inputs on different timescales. The microsecond-quick signal from the right ear must be reconciled with the slightly out-of-sync input from the left. These rapid responses contrast with the sluggish stream of hormones coursing through the bloodstream. The signals most important for this discussion, though, are the spikes, which are sharp rises in voltage that course through and between neurons. For cell-to-cell communication, spikes lasting a few milliseconds handle immediate needs. A neuron fires a spike after deciding that the number of inputs urging it to switch on outweigh the number telling it to turn off. When the decision is made, a spike travels down the cell's axon (somewhat akin to a branched electrical wire) to its tips. Then the signal is relayed chemically through junctions, called synapses, that link the axon with recipient neurons.

In each eye, 100 million photoreceptors in the retina respond to changing patterns of light. After the incoming light is processed by several layers of neurons, a million ganglion cells at the back of the retina convert these signals into a sequence of spikes that are relayed by axons to other parts of the brain, which in turn send spikes to still other regions that ultimately give rise to a conscious perception. Each axon can carry up to several hundred spikes each second, though more often just a few spikes course along the neural wiring. All that you perceive of the visual world—the shapes, colors and movements of everything around you—is coded into these rivers of spikes with varying time intervals separating them.

Monitoring the activity of many individual neurons at once is critical for making sense of what goes on in the brain but has long been extremely challenging. In 2010, though, E. J. Chichilnisky of the Salk Institute for Biological Studies in La Jolla, Calif., and his colleagues reported in *Nature* that they had achieved the monumental task of simultaneously recording all the spikes from hundreds of neighboring ganglion cells in monkey retinas. (*Scientific American* is part of Nature Publishing Group.) This achievement made it possible to trace the specific photoreceptors that fed into each ganglion cell. The growing ability to record spikes from many neurons simultaneously will assist in deciphering meaning from these codelike brain signals.

For years investigators have used several methods to interpret, or decode, the meaning in the stream of spikes coming from the retina. One method counts spikes from each axon separately over some period: the higher the firing rate, the stronger the signal. The information conveyed by a variable firing rate, a rate code, relays features of visual images, such as location in space, regions of differing light contrast, and where motion occurs, with each of these features represented by a given group of neurons.

IN BRIEF

Three pounds of nerve tissue underneath the skull are capable of perceiving, thinking and acting with a finesse that cannot be matched by any computer.

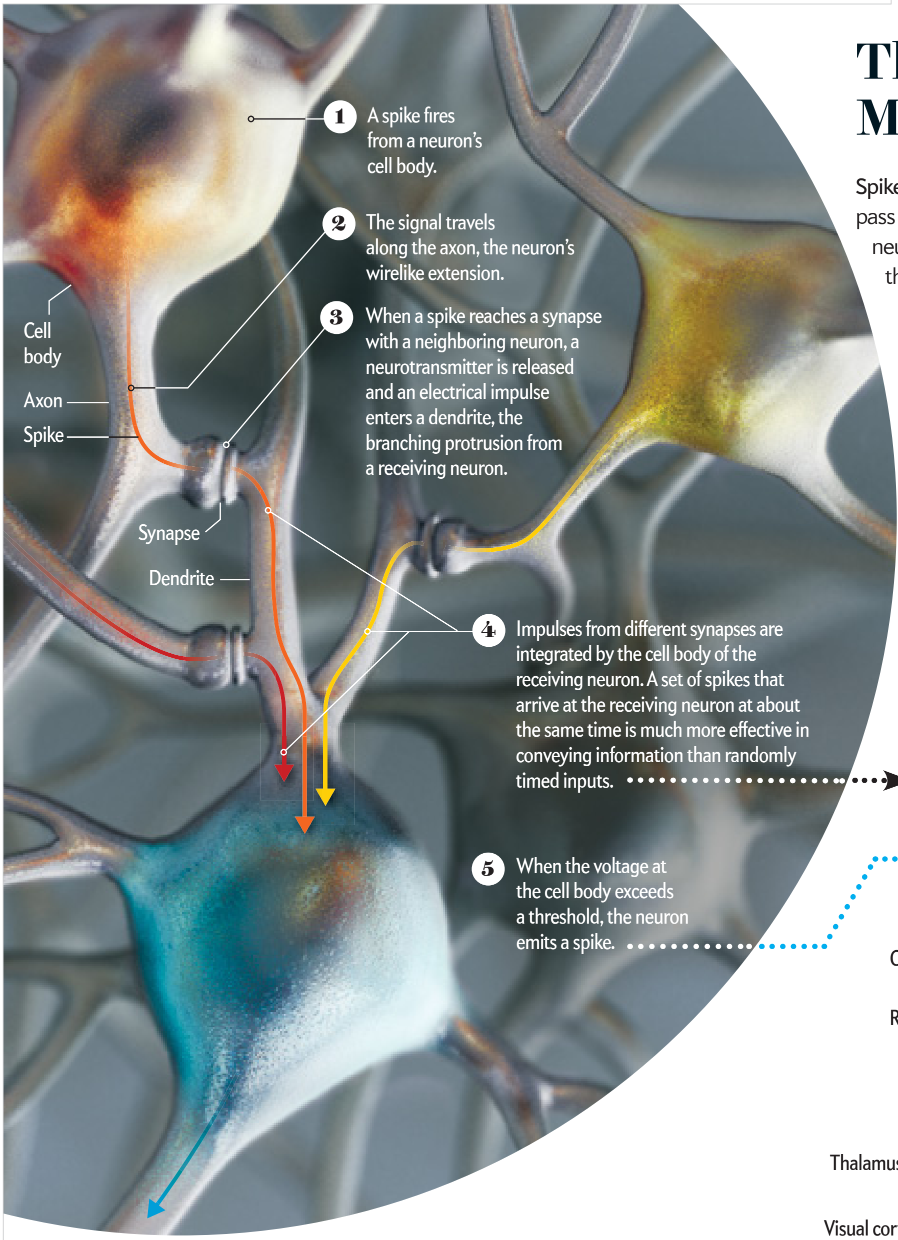
The brain achieves this feat of cognition, in part, by carefully timing the signals that flash across the trillions of connections that link billions of brain cells.

Seeing a flower pot causes groups of neurons to fire in a brief time interval to activate a part of the brain that registers that particular object at just that one moment.

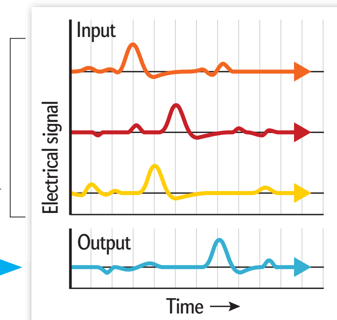
Understanding how this timing system works will both lead to better understanding of our behavior and enable the building of new computing and electronic equipment that, like the brain, functions more efficiently than conventional digital machines.

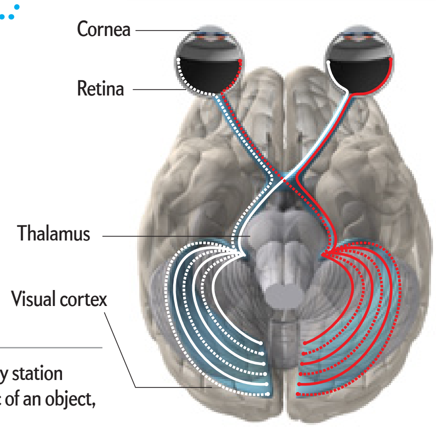
The Brain's Fast Messaging Link

Spikes—millisecond rises in voltage that pass down axons from cell bodies to other neurons—are the communication signals the brain uses to provide an immediate response to an event. New research has shown that coordinated timing of spikes lends efficiency to a network of brain cells that encompasses trillions of connections among neurons.



Spikes that arrive at a neuron within a narrow time window of a few milliseconds—shown below as colored blips—can trigger the firing of that neuron.





What the Eyes Tell the Brain
"Seeing" occurs when spikes generated by cells within the eye in response to an object move on to the relay station of the thalamus and then to the visual cortex. Properly timed spikes, each representing some characteristic of an object, such as color or spatial orientation, are integrated in the cortex to form a perception of the whole object.

Information is also transmitted by relative timing—when one neuron fires in close relation to when another cell spikes. Ganglion cells in the retina, for instance, are exquisitely sensitive to light intensity and can respond to a changing visual scene by transmitting spikes to other parts of the brain. When multiple ganglion cells fire at almost the same instant, the brain suspects that they are responding to an aspect of the same physical object. Horace Barlow, a leading neuroscientist at the University of Cambridge, characterized this phenomenon as a set of "suspicious coincidences." Barlow referred to the observation that each cell in the visual cortex may be activated by a specific physical feature of an object (say, its color or its orientation within a scene). When several of these cells switch on at the same time, their combined activation constitutes a suspicious coincidence because it may only occur at a specific time for a unique object. Apparently the brain takes such synchrony to mean that the signals are worth noting because the odds of such coordination occurring by chance are slim.

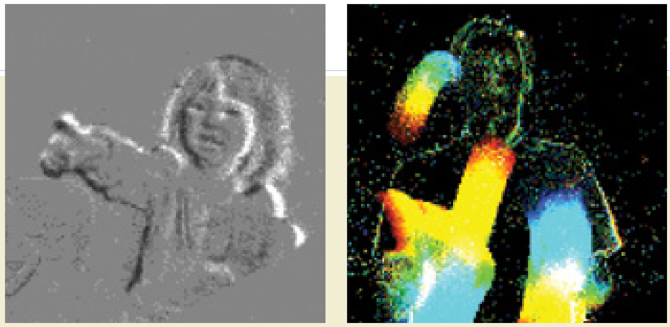
Electrical engineers are trying to build on this knowledge to create more efficient hardware that incorporates the principles

Illustration by Emily Cooper

APPLICATIONS

The Retina Inspires a New Kind of Camera

Technology emerges from studying the speed and efficiency of the brain's visual processing



IF IT MOVES, SHOOT IT: **The DVS captures only parts of the scene in which pixels change in brightness from one moment to the next. As contrast changes in the image of a child (*left*), pixels become brighter or darker. For the juggler (*right*), recent ball movements glow red and the oldest ones flash blue.**

Traditional digital video cameras are surprisingly inefficient. They snap 24 frames a second to capture the varying intensities of light that make up the different parts of a visual scene. Each pixel, or discrete picture element in an image, records the average intensity over the past 40 milliseconds, the time it takes a fast-hit tennis ball to move about 1.5 meters. As a result, the cameras produce an enormous flood of data that consumes a lot of processing time.

Aiming for more efficiency, one of us (Delbruck) and his colleagues at the Institute of Neuroinformatics at the University of Zurich have developed a new type of camera that mimics the way parts of the retina encode images for our brain. Like the retina, the camera—called the Dynamic Vision Sensor, or DVS—senses only the parts of a scene that change when any pixel detects a change in brightness from the existing recorded value. The camera can thus capture even fast-moving objects using just a trickle of data.

The pixels in the DVS behave something like certain retinal ganglion cells in that they also emit an electrical spike when brightness changes. The camera can record a shift of light intensity in the blink of a microsecond, so the DVS can track high-speed motion better than the millisecond speeds of ordinary cameras that capture a scene frame by frame.

Because of the sparse yet information-packed output of the DVS, the camera is ideal as a sentinel, a detector of anything that moves, whether a car, pedestrian traffic, or an elderly person who slips and falls. As a result of the camera's speed, the DVS has been incorporated into a robot that blocks balls shot at a goal, as well as a pencil-balancing robot, a car that follows a line drawn in chalk, and sensors that track particles in moving fluids or that interpret human gestures. The shoot-what-changes approach to processing visual information has started to attract broader interest among technology designers. A group at Weill Cornell Medical College and their collaborators recently reported on an artificial retina prosthesis that processes light using this method, a nod to the sparse elegance with which biology sometimes functions. *—T.S. and T.D.*

of spike timing when recording visual scenes. One of us (Delbruck) has built a camera that emits spikes in response to changes in a scene's brightness, which enables the tracking of very fast moving objects with minimal processing by the hardware to capture images [*see box above*].

INTO THE CORTEX

NEW EVIDENCE ADDS PROOF that the visual cortex attends to temporal clues to make sense of what the eye sees. The ganglion cells in the retina do not project directly to the cortex but relay signals through neurons in the thalamus, deep within the brain's midsection. This region in turn must activate 100 million cells in the visual cortex in each hemisphere at the back of the brain before the messages are sent to higher brain areas for conscious interpretation.

We can learn something about which spike patterns are most effective in turning on cells in the visual cortex by examining the connections from relay neurons in the thalamus to cells known as spiny stellate neurons in a middle layer of the visual cortex. In 1994 Kevan Martin, now at the Institute of Neuroinformatics at the University of Zurich, and his colleagues reconstructed the thalamic inputs to the cortex and found that they account for only 6 percent of all the synapses on each spiny stellate cell. How, then, everyone wondered, does this relatively weak visual input, a mere trickle, manage to reliably communicate with neurons in all layers of the cortex?

Cortical neurons are exquisitely sensitive to fluctuating inputs and can respond to them by emitting a spike in a matter of a few milliseconds. In 2010 one of us (Sejnowski), along with Hsi-Ping Wang and Donald Spencer of the Salk Institute and Jean-Marc Fellous of the University of Arizona, developed a detailed computer model of a spiny stellate cell and showed that even though a single spike from only one axon cannot cause one of these cells to fire, the same neuron will respond reliably to inputs from as few as four axons projecting from the thalamus if the spikes from all four arrive within a few milliseconds of one another. Once inputs arrive from the thalamus, only a sparse subset of the neurons in the visual cortex needs to fire to represent the outline and texture of an object. Each spiny stellate neuron has a preferred visual stimulus from the eye that produces a high firing rate, such as the edge of an object with a particular angle of orientation.

In the 1960s David Hubel of Harvard Medical School and Torsten Wiesel, now at the Rockefeller University, discovered that each neuron in the relevant section of the cortex responds strongly to its preferred stimulus only if activation comes from a specific part of the visual field called the neuron's receptive field. Neurons responding to stimulation in the fovea, the central region of the retina, have the smallest receptive fields—about the size of the letter e on this page. Think of them as looking at the world through soda straws. In the 1980s John Allman of the Cal-

COURTESY OF TOBI DELBRUCK (*left*); COURTESY OF PATRICK LICHTSTEINER AND TOBI DELBRUCK (*right*)

ifornia Institute of Technology showed that visual stimulation from outside the receptive field of a neuron can alter its firing rate in reaction to inputs from within its receptive field. This "surround" input puts the feature that a neuron responds to into the context of the broader visual environment.

Stimulating the region surrounding a neuron's receptive field also has a dramatic effect on the precision of spike timing. David McCormick, James Mazer and their colleagues at Yale University recently recorded the responses of single neurons in the cat visual cortex to a movie that was replayed many times. When they narrowed the movie image so that neurons triggered by inputs from the receptive field fired (no input came from the surrounding area), the timing of the signals from these neurons had a randomly varying and imprecise pattern. When they expanded the movie to cover the surrounding area outside the receptive field, the firing rate of each neuron decreased, but the spikes were precisely timed.

The timing of spikes also matters for other neural processes. Some evidence suggests that synchronized timing—with each spike representing one aspect of an object (color or orientation)—functions as a means of assembling an image from component parts. A spike for "pinkish red" fires in synchrony with one for "round contour," enabling the visual cortex to merge these signals into the recognizable image of a flower pot.

ATTENTION AND MEMORY

OUR STORY SO FAR has tracked visual processing from the photoreceptors to the cortex. But still more goes into forming a perception of a scene. The activity of cortical neurons that receive visual input is influenced not only by those inputs but also by excitatory and inhibitory interactions between cortical neurons. Of particular importance for coordinating the many neurons responsible for forming a visual perception is the spontaneous, rhythmic firing of a large number of widely separated cortical neurons at frequencies below 100 hertz.

Attention—a central facet of cognition—may also have its physical underpinnings in sequences of synchronized spikes. It appears that such synchrony acts to emphasize the importance of a particular perception or memory passing through conscious awareness. Robert Desimone, now at the Massachusetts Institute of Technology, and his colleagues have shown that when monkeys pay attention to a given stimulus, the number of cortical neurons that fire synchronized spikes in the gamma band of frequencies (30 to 80 hertz) increases, and the rate at which they fire rises as well. Pascal Fries of the Ernst Strüngmann Institute for Neuroscience in cooperation with the Max Planck Society in Frankfurt found evidence for gamma-band signaling between distant cortical areas.

Neural activation of the gamma-frequency band has also attracted the attention of researchers who have found that patients with schizophrenia and autism show decreased levels of this type of signaling on electroencephalographic recordings. David Lewis of the University of Pittsburgh, Margarita Behrens of the Salk Institute and others have traced this deficit to a type of cortical neuron called a basket cell, which is involved in synchronizing spikes in nearby circuits. An imbalance of either inhibition or excitation of the basket cells seems to reduce synchronized activity in the gamma band and may thus explain some of the physiological underpinnings of these neurological disorders. Interestingly, patients with schizophrenia do not perceive some visual illusions, such as the tilt illusion, in which a person typically misjudges the tilt of a line because of the tilt of nearby lines. Similar circuit abnormalities in the prefrontal cortex may be responsible for the thought disorders that accompany schizophrenia.

When it comes to laying down memories, the relative timing of spikes seems to be as important as the rate of firing. In particular, the synchronized firing of spikes in the cortex is important for increasing the strengths of synapses—an important process in forming long-term memories. A synapse is said to be strengthened when the firing of a neuron on one side of a synapse leads the neuron on the other side of the synapse to register a stronger response. In 1997 Henry Markram and Bert Sakmann, then at the Max Plank Institute for Medical Research in Heidelberg, discovered a strengthening process known as spike-timing-dependent plasticity, in which an input at a synapse is delivered at a frequency in the gamma range and is consistently followed within 10 milliseconds by a spike from the neuron on the other side of the synapse, a pattern that leads to enhanced firing by the neuron receiving the stimulation. Conversely, if the neuron on the other side fires within 10 milliseconds before the first one, the strength of the synapse between the cells decreases.

Some of the strongest evidence that synchronous spikes may be important for memory comes from research by György Buzsáki of New York University and others on the hippocampus, a brain area that is important for remembering objects and events. The spiking of neurons in the hippocampus and the cortical areas that it interacts with is strongly influenced by synchronous oscillations of brain waves in a range of frequencies from four to eight hertz (the theta band), the type of neural activity encountered, for instance, when a rat is exploring its cage in a laboratory experiment. These theta-band oscillations can coordinate the timing of spikes and also have a more permanent effect in the synapses, which results in long-term changes in the firing of neurons.

A GRAND CHALLENGE AHEAD

NEUROSCIENCE IS AT A TURNING POINT as new methods for simultaneously recording spikes in thousands of neurons help to reveal key patterns in spike timing and produce massive databases for researchers. Also, optogenetics—a technique for turning on genetically engineered neurons using light—can selectively activate or silence neurons in the cortex, an essential step in establishing how neural signals control behavior. Together, these and other techniques will help us eavesdrop on neurons in the brain and learn more and more about the secret code that the brain uses to talk to itself. When we decipher the code, we will not only achieve an understanding of the brain's communication system, we will also start building machines that emulate the efficiency of this remarkable organ. SA

MORE TO EXPLORE

Terry Sejnowski's 2008 Wolfgang Pauli Lectures on how neurons compute and communicate: **www.podcast.ethz.ch/podcast/episodes/?id=607**

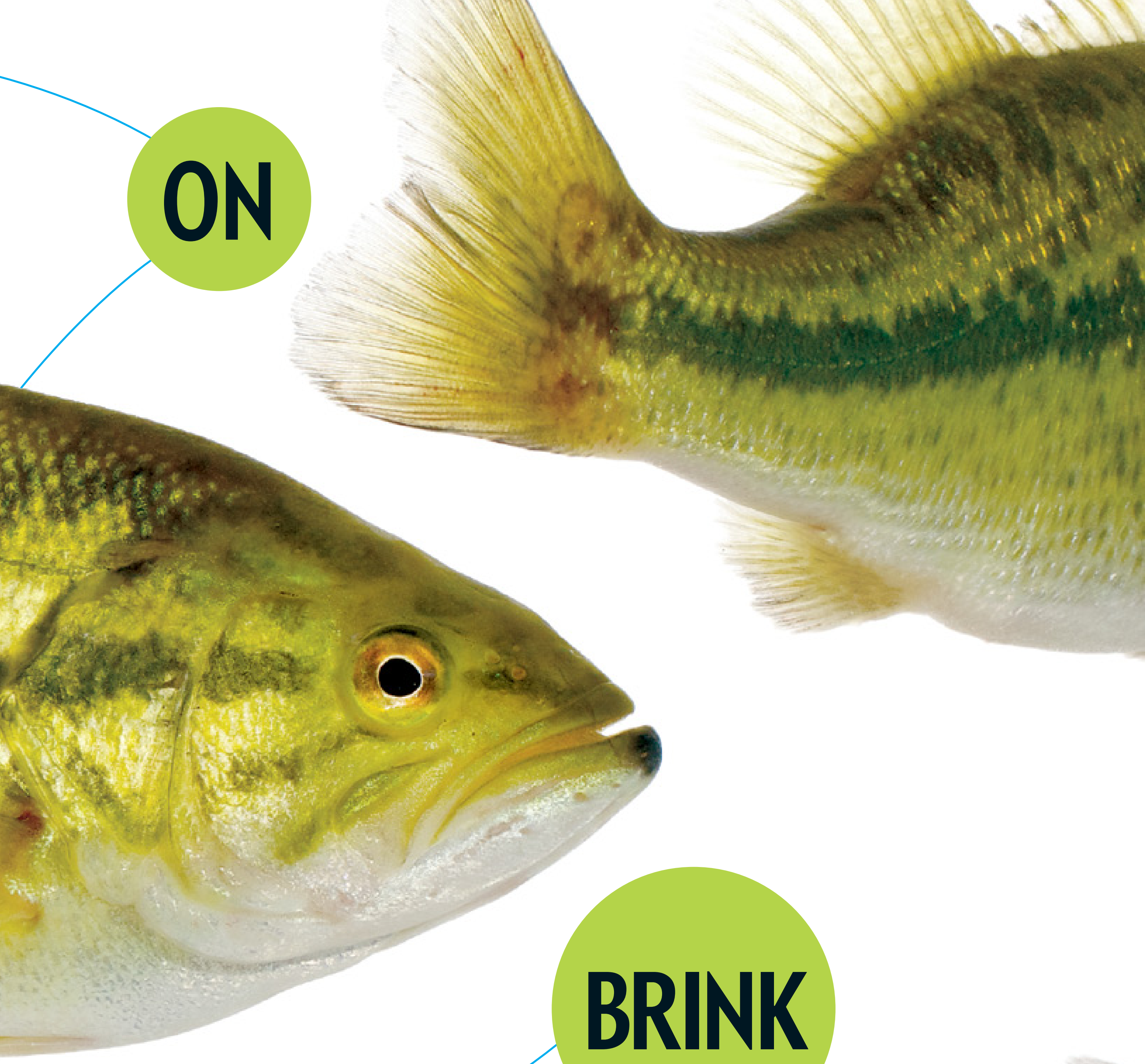
Neuromorphic Sensory Systems. Shih-Chii Liu and Tobi Delbruck in *Current Opinion in Neurobiology,* Vol. 20, No. 3, pages 288–295; June 2010. **http://tinyurl.com/bot7ag8**

SCIENTIFIC AMERICAN ONLINE
Watch a video about a motion-sensing video camera that uses spikes for imaging at **ScientificAmerican.com/oct2012/dvs**

ENVIRONMENT

ECOSYSTEMS

THE



ON [THE] BRINK

To keep jellyfish, fungi and other creatures from overtaking healthy habitats, scientists are exploring food webs and tipping points

By Carl Zimmer

Photograph by David Liittschwager

Carl Zimmer is a frequent contributor to the *New York Times* and is author and co-author of a dozen books, including *Evolution: Making Sense of Life,* a textbook he co-authored with biologist Douglas J. Emlen.

PETER LAKE LIES DEEP IN A MAPLE FOREST NEAR THE WISCONSIN-MICHIGAN border. One day in July 2008 a group of scientists and graduate students led by ecologist Stephen Carpenter of the University of Wisconsin–Madison arrived at the lake with some fish. One by one, they dropped 12 largemouth bass into the water. Then they headed for home, leaving behind sensors that could measure water clarity every five minutes, 24 hours a day.

The scientists repeated the same trip two more times in 2009. Each time they dropped 15 more bass into the water. Months passed. The lake cycled through the seasons. It froze over, thawed out and bloomed again with life. Then, in the summer of 2010, Peter Lake changed dramatically. Before the scientists started their experiment, the lake abounded in fathead minnows, pumpkinseeds and other small fish. Now, however, those once dominant predators were rare, for the most part eaten by the largemouth bass. The few survivors hid in the shallows. Water fleas and other tiny animals that the small fish once devoured were now free to flourish. And because these diminutive animals graze on algae, the lake water became clearer. Two years later the ecosystem remains in its altered state.

Peter Lake's food web has flipped, shifting from a longstanding arrangement to a new one. Carpenter triggered the switchover on purpose, as part of an experiment he is running on the factors that lead to persistent changes in the mix of organisms eating and being eaten by one another. Yet in recent decades food webs across the world have also been flipping, often unexpectedly, on a far greater scale. Jellyfish now dominate the waters off the coast of Namibia. Hungry snails and fungi are overrunning coastal marshes in North Carolina, causing them to disintegrate. In the northwestern Atlantic, lobsters are proliferating while cod have crashed.

Whether by fishing, converting land into farms and cities, or warming the planet, humanity is putting tremendous stresses on the world's ecosystems. As a result, ecologists expect many more food webs to flip in the years ahead. Predicting those sudden changes is far from straightforward, however, because food webs can be staggeringly complex.

That is where Carpenter comes in. Taking advantage of 30 years of ecological research at Peter Lake, Carpenter and his colleagues developed mathematical models of ecological networks that allowed them to pick up early-warning signs of the change that was coming, 15 months before its food web flipped. "We could see it a good long ways in advance," Carpenter says.

With the help of such models, he and other scientists are beginning to decipher some of the rules that determine whether a food web will remain stable or cross a threshold and change substantially. They hope to use their knowledge of those rules to monitor the state of ecosystems so that they can identify ones at risk of collapse. Ideally, an early-warning system would tell us when to alter human activities that are pushing an ecosystem toward a breakdown or would even allow us to pull ecosystems back from the brink. Prevention is key, they say, because once ecosystems pass their tipping point, it is remarkably difficult for them to return.

MATHEMATICAL PREDATORS

CARPENTER'S WORK builds on a century of basic research by ecologists who have sought to answer a simple question: Why are the populations of different species the way they are? Why, for example, are there so many flies and so few wolves? And why do the sizes of fly populations vary greatly from one year to the next? To find an answer, ecologists began to diagram food webs, noting who ate whom and how much each one ate. Yet food

IN BRIEF

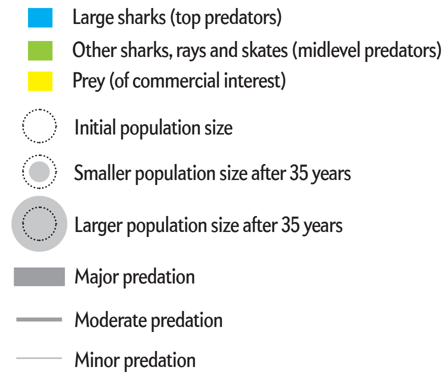
Food webs are complex, but mathematical models can reveal critical links that, if disturbed, can cause the webs to flip to a different state, including collapse.

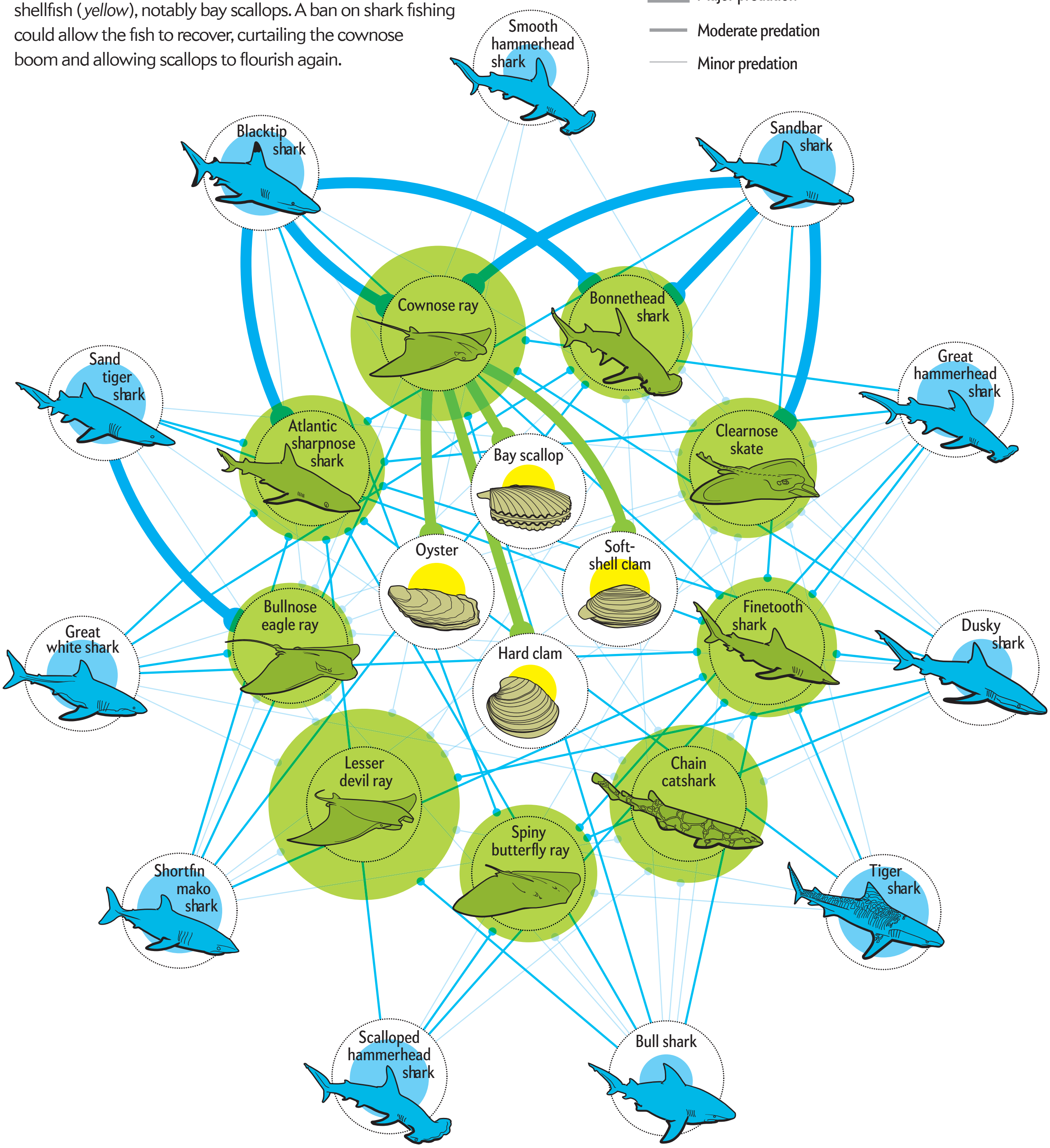
Once the flipping of food webs takes place, they are often unlikely to return to their original state.

Experiments in Peter Lake and Paul Lake near the Michigan-Wisconsin border are showing that models can predict a flip before it occurs, giving ecologists a chance to alter an ecosystem and pull it back from the brink.

Fewer Sharks, Scallops

After decades of thinking that food webs are structured from the bottom up, researchers are finding that top predators often control the chain—directly and indirectly. A study by Julia Baum, now at the University of Victoria in British Columbia, and others shows that overfishing of large sharks (*blue*) off the eastern U.S. has allowed midlevel predators (*green*) to grow in number, especially the cow-nose ray. The expanded population, in turn, has devastated certain shellfish (*yellow*), notably bay scallops. A ban on shark fishing could allow the fish to recover, curtailing the cownose boom and allowing scallops to flourish again.





SOURCES: "CASCADING TOP-DOWN EFFECTS OF CHANGING OCEANIC PREDATOR ABUNDANCES," BY JULIA K. BAUM AND BORIS WORM, IN *JOURNAL OF ANIMAL ECOLOGY*, VOL. 78, NO. 4; JULY 2009, AND "CASCADING EFFECTS OF THE LOSS OF APEX PREDATORY SHARKS FROM A COASTAL OCEAN," BY RANSOM A. MYERS, JULIA K. BAUM, TRAVIS D. SHEPHERD, SEAN P. POWERS AND CHARLES H. PETERSON, IN *SCIENCE*, VOL. 315; MARCH 30, 2007

Illustrations by Portia Sloan Rollings, Graphic by Jen Christiansen

webs can encompass dozens, hundreds or thousands of species; their complexity often turned attempted diagrams into hopeless snarls.

To make sense of the snarls, ecologists have turned food webs into mathematical models. They write an equation for the growth of one species by linking its reproduction rate to how much food it can obtain and how often it gets eaten by other species. Because all those variables can change, solving the equations for even simple food webs has proved overwhelming. Fortunately, the rise of fast, cheap computers has recently allowed ecologists to run simulations of many different kinds of ecosystems.

Out of this work, ecologists discovered some key principles operating in real food webs. Most food webs, for instance, consist of many weak links rather than a few strong ones. Two species are strongly linked if they interact a lot, such as a predator that consistently devours huge numbers of a single prey. Species that are weakly linked interact occasionally: a predator snacks every now and then on various species. Food webs may be dominated by numerous weak links because that arrangement is more stable over the long term. If a predator can eat several species, it can survive the extinction of one of them. And if a predator can move on to another species that is easier to find when a prey species becomes rare, the switch allows the original prey to recover. The weak links may thus keep species from driving one another to extinction. "You see it over and over again," says Kevin McCann, an ecologist at the University of Guelph in Ontario.

Mathematical models have also revealed vulnerable points in food webs, where small changes can lead to big effects throughout entire ecosystems. In the 1960s, for example, theoreticians proposed that predators at the top of a food web exerted a surprising amount of control over the size of populations of other species—including species they did not directly attack. The idea of this top-down control by a small fraction of animals in an ecosystem was greeted with skepticism. It was hard to see how a few top predators could have such a great effect on the rest of their food web.

But then we humans began running unplanned experiments that put this so-called trophic cascade hypothesis to the test. In the ocean, we fished for top predators such as cod on an industrial scale, while on land, we killed off large predators such as wolves. We introduced invasive species such as rats to islands and gave a variety of other shocks to the world's ecosystems. The results of these actions vindicated the key role of predators and the cascading effects they can have from the top of a food web on down.

Ecologists realized that, as predicted, changes in certain predators had massive impacts on food webs. The slaughter of wolves around Yellowstone National Park led to a boom in elk and other herbivores. The elk feasted on willow and aspen leaves, killing many trees. Likewise, off the eastern U.S. coast, fishers have devastated oyster and scallop populations without catching a single one. Instead they have killed sharks in huge numbers, allowing the smaller predatory fish the sharks fed on to thrive. The population of cownose rays, for example, has exploded. Cownose rays feed on bottom-dwelling shellfish, and as a result, their boom has led to a crash in oysters and scallops.

UNINTENDED CUT: Removing gray wolves from Yellowstone National Park allowed a boom in elk, which dined on aspen leaves, killing many young trees.

HANS REINHARD *Photo Researchers, Inc.* (wolf); GERRY ELLIS *Getty Images* (elk); DAVID SUCSY *Minden Pictures* (trees)

THE STICKY SWITCH

MANY OF THESE FLIPS have taken ecologists by surprise. And they have realized that forecasting when a food web will change drastically is important because once it does, it often sticks; returning a food web to its original state is hard. "Getting back is really, really difficult," says ecologist Villy Christensen of the University of British Columbia.

In the northwestern Atlantic, for example, cod fisheries collapsed in the early 1990s. Cod are voracious predators, and with their disappearance came a boom in their prey, including sprats, capelins, young lobsters and snow crabs. To try to allow cod to recover, managers put strict limits on cod fishing or even banned it altogether. The mathematical models they relied on indicated that if the fish were left unmolested, they would be able to lay enough eggs and grow fast enough to rebuild their population.

"The predictions for recovery were on the order of five to six years," says Kenneth Frank, a research scientist at Fisheries and Oceans Canada at the Bedford Institute of Oceanography who studies cod fisheries off the coast of Nova Scotia and Newfoundland. The predictions were wrong, however. Even after six years, the cod showed no sign of recovery. Instead the species languished at a few percent of its precollapse population.

Frank and his colleagues have now figured out why: the initial estimates were based only on how fast cod can reproduce, not on how the whole food web is organized. Adult cod feed on sprats and capelins and other prey known collectively as forage fish. The forage fish, in turn, eat tiny animals known as zooplanktons, including the eggs and larvae of cod themselves.

Before cod were overfished, they kept the forage fish in check, so that the small fish could not eat enough eggs and larvae to put a dent in the cod population. Once humans lowered the cod population, though, the tables were turned. The forage fish boomed and could devour a substantial fraction of the young cod. Even without humans fishing them, the cod were unable to rebound.

Only now are Frank and his co-workers seeing signs of a de-

layed recovery. After falling to as low as 1 percent of their precrash levels, the cod have risen in recent years to 30 percent. The key, Frank says, is that the forage fish have exploded to such high numbers that they are outstripping their own food supply and are starting to crash. Now that their population has dropped, cod eggs and larvae have a much better chance to reach adulthood. If cod can return to their former levels, they will be able to keep the populations of forage fish down once more. "That's the trajectory they're on, but there are lots of surprises because these ecosystems are so complex," Frank says.

Food webs will continue to flip around the world. Some will do so because of hunting and fishing, but others will be buffeted by other forces. For example, lionfish, native to the Pacific, became popular as pets in the U.S., but East Coast owners who grew tired of them began dumping them into the Atlantic, where they are now menacing Caribbean coral reefs. They are eating so many small prey species that ecologists predict they will outcompete and drive down many of the native predators, including sharks. Climate change is also altering food webs, in some cases by shifting the ranges of predators and their prey. No matter what the driver of food web changes, they may be able to push the ecosystems over major thresholds. And if those ecosystems have sticky switches, it will be very hard to restore them.

CARPENTER IS DEVELOPING AN EARLY-WARNING SYSTEM THAT CAN REVEAL WHEN A FOOD WEB IS ABOUT TO FLIP AND OFFER GUIDANCE ABOUT HOW TO PULL IT BACK FROM THE BRINK.

EARLY WARNING PREVENTS COLLAPSE

SOME SCIENTISTS SAY that preventing food webs from switching is a more effective strategy than trying to restore ones that have flipped. They believe an ounce of ecological prevention may be worth a pound of cure. Carpenter and his colleagues have been developing an early-warning system that can reveal when ecological switches are about to happen and offer some guidance about how to pull an ecosystem back from the tipping point.

"Ecologists had always thought these things were completely unpredictable," Carpenter says. That is why, eight years ago, he and his colleagues began to create equations that could capture how ecosystems work. They included variables for such factors as the reproduction rate of species and the rate at which different species eat one another. These equations produced ecosystem models that could reach tipping points at which they would suddenly convert into a new state, just as real ecosystems do.

The scientists could also see subtle yet distinctive patterns developing long before the virtual ecosystems abruptly changed—an ecological version of distant rumbles that precede a storm. One pattern that surfaced, for example, was that when an ecosystem was disturbed—say, by a sudden swing in temperature or a disease outbreak—it began to take longer than usual to return to its regular state. "As it gets closer to the tipping point, it recovers more slowly from perturbations," says Marten Scheffer, an ecologist at Wageningen University in the Netherlands who has worked with Carpenter on early-warning systems.

Scheffer, Carpenter and their co-workers are testing their models in a range of experiments. Some have taken place in the carefully controlled confines of laboratories. Carpenter's experiment in Peter Lake was the first time they had put the early-warning system to a test in a natural ecosystem. Once the scientists started to stock Peter Lake, they performed daily recordings of the zooplanktons, phytoplanktons and fishes in the water. They also monitored nearby Paul Lake, similar in size, which they did not manipulate. Any changes that occurred in both lakes would presumably be the result of external factors in the climate. In the summer of 2009 the scientists began to see rapid rises and falls in the chlorophyll levels in Peter Lake. The lake's jitters matched the patterns that come before an ecosystem flips in Carpenter's models. Paul Lake, meanwhile, showed no such change.

Carpenter and his colleagues hope to develop monitoring systems that can detect similarly telltale fluctuations that foreshadow an imminent change in other ecosystems, from wetlands to forests to oceans. "There are many tricky aspects to it, but it does work," Scheffer says.

The goal, of course, is to know when we are pushing an ecosystem to the brink, so we can stop pushing. To test this idea, Carpenter is manipulating Peter Lake again. Instead of adding top predators, this time he is adding fertilizer, which will likely lead to a boom of algae. That, in turn, will trigger changes throughout the lake's ecosystem. Carpenter expects that a number of bigger fish species—including those largemouth bass—will crash as a result and then remain stuck at low levels. He also expects to get warning signs of this change months in advance, in the form of chlorophyll fluctuations and other subtle patterns. Once he sees those signs, Carpenter will stop supplying the extra fertilizer. If he is right, the ecosystem will return to its normal state instead of flipping. For comparison, he will add fertilizer to nearby Tuesday Lake, but he will not stop when he does at Peter Lake. Paul Lake will again be left untreated, as a control.

Carpenter is optimistic that the early-warning system he is developing will work not just in isolated lakes but in any ecosystem, thanks to the way ecological networks are organized. Yet success would not mean that predicting a flip would be certain. The equations that he and his colleagues have developed suggest that some disturbances will be so dramatic and fast that they will not leave time for ecologists to notice that trouble is coming. "Surprises will continue," Carpenter says, "although the early-warning system does provide the opportunity to anticipate some surprises before they happen." SA

MORE TO EXPLORE

Human Involvement in Food Webs. Donald R. Strong and Kenneth T. Frank in *Annual Review of Environment and Resources,* Vol. 35, pages 1–23; November 2010.

Trophic Cascades: Predators, Prey, and the Changing Dynamics of Nature. Edited by John Terborgh and James A. Estes. Island Press, 2010.

Food Webs. Kevin S. McCann. Princeton University Press, 2011.

SCIENTIFIC AMERICAN ONLINE
For an interactive graphic showing predator effects on food webs in the Adriatic Sea, go to **ScientificAmerican.com/oct2012/zimmer**

PHYSICS

The Higgs at Last

After a three-decade search, scientists appear to have found the elusive particle. Its peculiar properties suggest a new era in physics could be about to dawn

By Michael Riordan, Guido Tonelli and Sau Lan Wu

Illustration by Benjamin Simon and Dirk Schuster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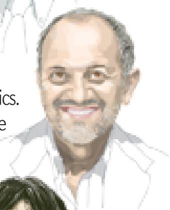
Michael Riordan is a historian of science and the author of numerous books, including *The Hunting of the Quark* (Simon & Schuster, 1987). He is writing a history of the ill-fated Superconducting Super Collider.



Guido Tonelli is a professor at the University of Pisa in Italy and a researcher at Italy's National Institute of Nuclear Physics. He has been working on the CMS experiment at CERN since 1993 and served as its spokesperson in 2010 and 2011.

Sau Lan Wu has been searching for the Higgs boson for more than 20 years, first at the LEP collider and since 1993 as a member of the ATLAS experiment at CERN. She is Enrico Fermi Distinguished Professor of Physics at the University of Wisconsin-Madison.

Late on the evening

of June 14, 2012, groups of graduate students and postdoctoral researchers working on the Large Hadron Collider began peering into a just opened data cache. This huge machine at CERN, the European laboratory for particle physics near Geneva, had been producing tremendous amounts of data in the months since it awoke from its winter-long slumber. But the more than 6,000 physicists who work on the LHC's two largest experiments were wary of unintentionally adding biases to their analysis. They had agreed to remain completely unaware of the results—performing what are called "blind" analyses—until mid-June, when all would suddenly be revealed in a frenzy of nocturnal activity.

Many of the young scientists worked through that night to untangle the newly freed threads of evidence. Although the LHC is a giant collider feeding multiple experiments, only the two largest ones—ATLAS and CMS—had been tasked with finding the Higgs boson, the long-sought particle that would complete the Standard Model of particle physics, the theoretical description of the subatomic world. Each massive detector records the subatomic debris spewing relentlessly from proton collisions in its midst; a detailed, independent accounting of these remnants can reveal fleeting new phenomena, including perhaps the elusive Higgs boson. Yet the detectors have to sift through the particle tracks and energy deposits while enduring a steady siege of low-energy background particles that threaten to swamp potentially interesting signals. It is like drinking from a fire hose while trying to ferret out a few tiny grains of gold with your teeth.

Fortunately, the scientists knew what they were looking for. After the LHC's disastrous start—an electrical splice between two magnets warmed and melted just nine days after the LHC came online in 2008, triggering a powerful spark that punctured the surrounding vessel, released tons of helium and ripped scores of costly superconducting magnets from their mounts—the collider had been collecting reams of data during 2011, enough to pick up an early hint of a Higgs signal.

After that run ended in October for its scheduled winter shutdown, Fabiola Gianotti, spokesperson for ATLAS, and one of us (Tonelli), then spokesperson for CMS, delivered a special seminar to an overflowing audience in the main CERN auditorium. Both detectors independently found suggestive bumps in the data.

What's more, these telltale hints of a Higgs boson corroborated one another. Both ATLAS and CMS reported several dozen

IN BRIEF

The Higgs boson, the last missing piece of the Standard Model of particle physics, had for many decades eluded physicists' increasingly elaborate efforts to detect its presence.

Two giant experiments at CERN's Large Hadron Collider had found tantalizing hints of the Higgs in late 2011. At that time, physicists hoped that the spring 2012 run would lead to a discovery.

Physicists hid the data from the spring run from even themselves, "blinding" their analyses so as to not introduce bias. In mid-June they took the first look at the new evidence.

The "Higgs-like" particle that emerged has many of the properties that physicists were looking for. It also held some early surprises that could point the way to the future of physics.

events above the expected background in which two photons came blazing out with combined energies of 125 billion electron volts, or 125 GeV. (GeV is the standard unit of mass and energy in particle physics, about equal to a proton mass.) If proton collisions had created short-lived Higgs bosons, they could have decayed into these photons. Each experiment also found a few surplus events in which four charged leptons (electrons or muons) carried off similar total energies. These could also have been the result of a Higgs [*see box on next page*]. Such a concurrence of signals was unprecedented. It suggested that something real was beginning to appear in the data.

Yet given the stringent norms of particle physics, none of the signals observed in 2011 were strong enough to allow for claims of a "discovery." Data peaks and bumps like this had often proved ephemeral, mere random fluctuations. And the successful spring 2012 run, which generated more proton collisions in 11 weeks than had come in during all of 2011, could easily have washed out the nascent data peaks, smothering them in background noise.

Of course, the opposite could occur, too. If the bumps were the result of an actual Higgs boson, not just a cruel statistical artifact, all the new data gave researchers a good chance of being able to claim an official discovery—ending this decades-long search and beginning a whole new era in our understanding of matter and the universe.

Hushed conversation suggested something big was building up. Pressure to go public swelled.

A THREE-DECADE SEARCH

NEVER JUST ANOTHER PARTICLE, the Higgs boson is the cornerstone of a grand intellectual edifice known as the Standard Model, the interwoven set of theories that constitute modern particle physics. This particle's existence had been suggested in 1964 by Peter W. Higgs of the University of Edinburgh as the result of a subtle mechanism—independently conceived by François Englert and Robert Brout in Brussels plus three theorists in London—that endows elementary particles with mass. The Higgs boson is the physical manifestation of an ethereal fluid (called the Higgs field) that permeates every corner of the cosmos and imbues elementary particles with their distinctive masses. With the discovery of quarks and gluons in the 1970s and the massive, weak-force-bearing *W* and *Z* bosons during the early 1980s, most of the elements of the Standard Model had fallen neatly into place.

Although theorists asserted that the Higgs boson—or something like it—must exist, they could not predict what its mass might be. For this and other reasons, researchers had few clues about where to look for it. An early candidate, weighing in at less than nine times the proton mass, turned up in 1984 at a refurbished, low-energy electron-positron collider in Hamburg, Germany. Yet the evidence withered away after further study.

Most theorists agreed that the Higgs mass should be 10 to 100 times higher. If so, discovering it would require a much larger and more energetic particle collider than even the Fermi National Laboratory's Tevatron, a six-kilometer proton-antiproton collider completed in 1983. That same year CERN began building the billion-dollar Large Electron Positron (LEP) collider, boring a 27-kilometer circular tunnel that crossed the French-Swiss border four times near Geneva. Although LEP had other important physics goals, the Higgs boson was high on its target list.

U.S. particle physicists, encouraged by the Reagan administration to "think big," pushed through grandiose plans for a much larger, multibillion-dollar machine, the Superconducting Super Collider (SSC), in the late 1980s. With a proton-proton collision energy of 40 trillion electron volts (40 TeV, or 40,000 GeV), the SSC was designed to track down the Higgs boson even if it were to come in at a mass near 1,000 GeV.

But after the SSC's projected price tag nearly doubled to $10 billion, Congress voted to kill it in 1993. Dismayed, U.S. Higgs hunters thereafter turned back to Fermilab and CERN to pursue this research. Discoveries and precision measurements made at LEP and the Tevatron soon implied that the Higgs boson should be no more than 200 GeV, which put it potentially within reach of these colliders. In over a decade of searching, however, physicists found no lasting evidence for Higgs-like data bumps.

During the final LEP runs in the summer of 2000, physicists decided to push the collision energy beyond what the machine was designed to handle. That is when hints of a Higgs boson began appearing. In September two of the four LEP experiments reported evidence for a handful of events with a *Z* boson plus another mystery particle that decayed into two bottom quarks—a particle that looked a lot like a 115-GeV Higgs boson. CERN's then director Luciano Maiani granted the machine a six-week stay of execution that autumn, but during that period researchers could unearth only one more candidate event. It was not sufficient. After a heated debate, Maiani decided to shut LEP down and begin its planned conversion into the LHC, a machine designed to find the Higgs boson.

CLOSING IN ON DISCOVERY

THE LHC IS the most spectacular collection of advanced technology ever assembled. Built inside the original LEP tunnel by hundreds of accelerator physicists and engineers led by project manager Lyndon Evans, it uses little left from that collider. Its principal components include more than 1,200 superconducting dipole magnets—shiny, 15-meter-long cylinders worth nearly $1 million each. Probably the most sophisticated components ever mass-produced, by firms in France, Germany and Italy, they harbor twin beam tubes that are flanked by niobium-titanium magnet coils bathed in liquid helium at 1.9 kelvins, or –271 degrees Celsius. Inside, twin proton beams circulate in both directions at energies up to 7 TeV and velocities approaching light speed.

The beams resemble those of a pulsed laser rather than a flashlight. Each consists of almost 1,400 "bunches," containing up to 150 billion protons apiece—about the number of stars in the Milky Way. Under normal operations, 10 to 30 proton collisions occur during each bunch crossing. That corresponds, however, to around half a billion collisions per second.

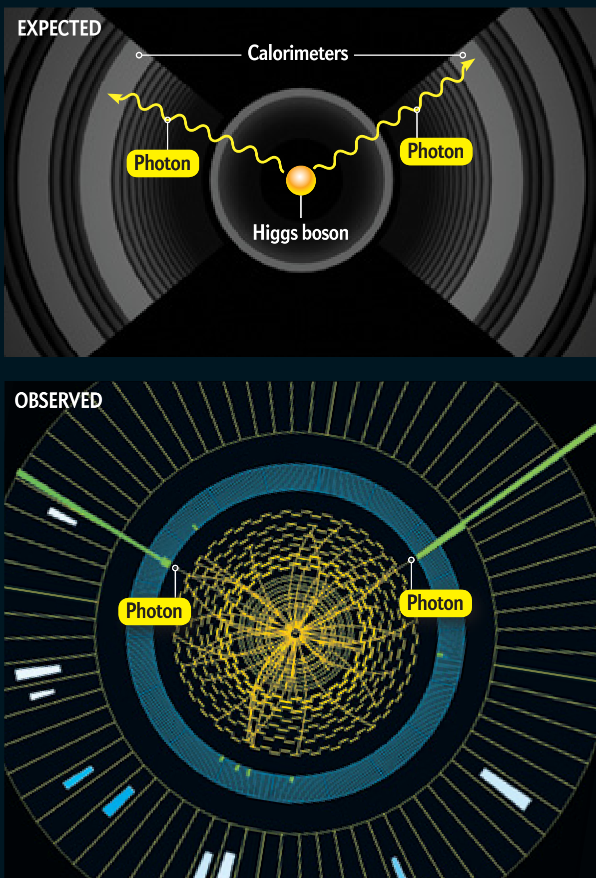
Proton collisions are far messier than electron-positron collisions. Theorist Richard Feynman of the California Institute of Technology once compared the process to smashing garbage cans into garbage cans, which means that lots of junk comes out. Pro-

The Delicate, Rare Fingerprints of the Higgs

The Higgs boson is an extremely unstable particle that quickly decays via a number of different processes, or "modes." Unfortunately, many decay modes are indistinguishable from the thunderous din of ordinary background events that result from 500 million proton-proton collisions every second. The ATLAS and CMS experiments are designed to spot the occasional interesting

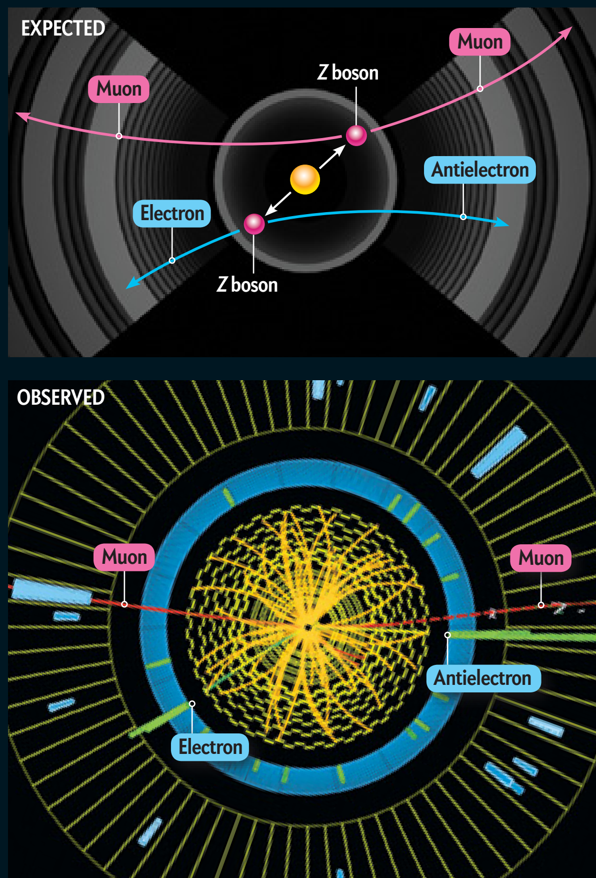
Photons

Each detector includes multiple calorimeters, devices for measuring the energy of particles. The innermost calorimeter is particularly alert for photons. These are absorbed in the calorimeter and create tiny electrical signals. If a Higgs decays into two photons, the detector can measure their total energy at extremely high accuracy, which helps to precisely reconstruct the mass of the newly found particle.



Z Bosons

The Higgs may decay into a pair of *Z* bosons, each of which can decay into an electron paired with an oppositely charged antielectron or two muons. An inner tracker and calorimeter measure the electrons, while muons fly out, leaving footprintlike tracks as they go. High magnetic fields bend the path of electrons and muons during their trip, allowing for a high-resolution measurement of their energy and the original Higgs mass.



tons are composite objects made of quarks and gluons; in the most interesting events, two gluons collide at energies above 100 GeV—and occasionally up to 1 TeV. Physicists, aided by sophisticated detectors, custom-built electronics and state-of-the art computers, try to sift the few events corresponding to interesting physics from the billions of dull, uninteresting ones.

The ATLAS and CMS experiments cannot observe a Higgs boson directly—it would decay into other particles far too quickly. They look for evidence that it was created inside. Depending on the Higgs boson's mass, it could decay into lighter particles in a variety of ways [*see box above*]. In 2011 attention began to focus on its rare decays into two photons and four charged leptons because these signals would stand out starkly against the tremendous backgrounds that could easily swamp a Higgs signal.

The year's delay caused by the 2008 magnet disaster gave Fermilab physicists one last shot at making a Higgs discovery. Just before the scheduled Tevatron shutdown in September 2011, the CDF and D-Zero experiments at the collider reported small excesses of events in which bottom quark pairs appeared at combined energies from 125 to 155 GeV. But as in the LEP closure, the

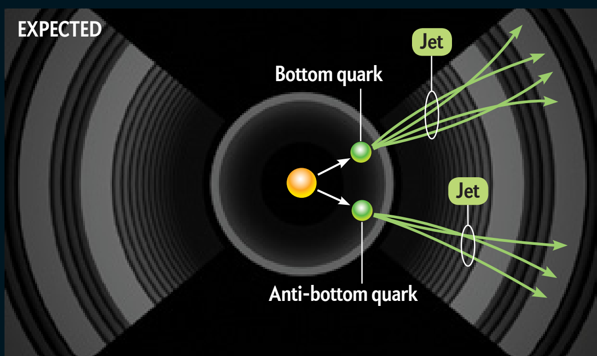
CERN (*observed signals from CMS detector*)

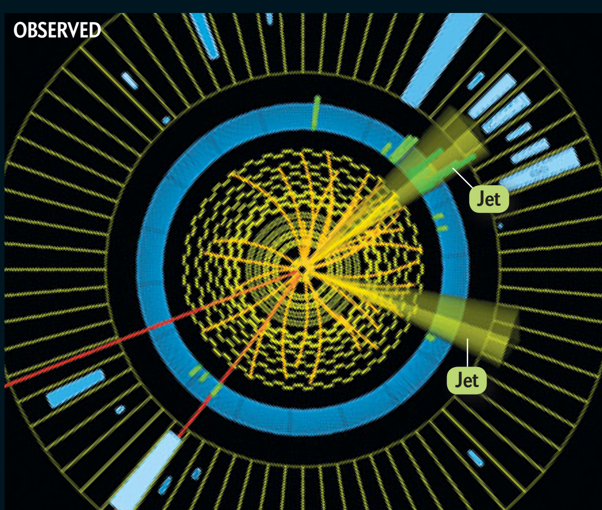
Illustration by George Retseck

events that might come from the Higgs decay and throw much of the rest away. The drawings below show four of the most important decay modes that experiments use to search for the Higgs, along with images of actual Higgs-like signals that CMS observed in the 2011 and 2012 runs. (Because the discovery is statistical in nature, no single event can be used as definitive proof.)

Bottom Quarks

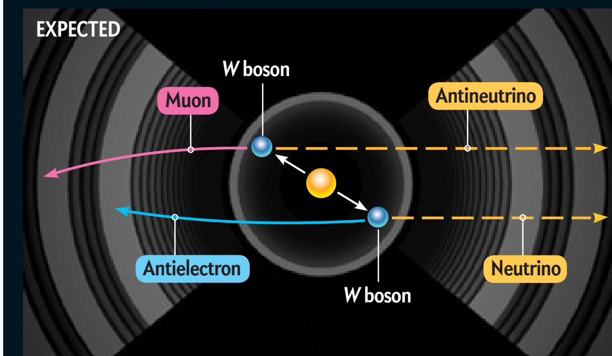
The Higgs can also decay to a bottom quark and its antiparticle, each of which decays into a tight "jet" of secondary particles called hadrons (composite particles made of quarks). These hadrons fly through the detector's inner layers and deposit their energy in the outer calorimeters. Unfortunately, many ordinary collisions also generate jets of hadrons from bottom quarks, which makes it difficult to separate these Higgs events out from the background.

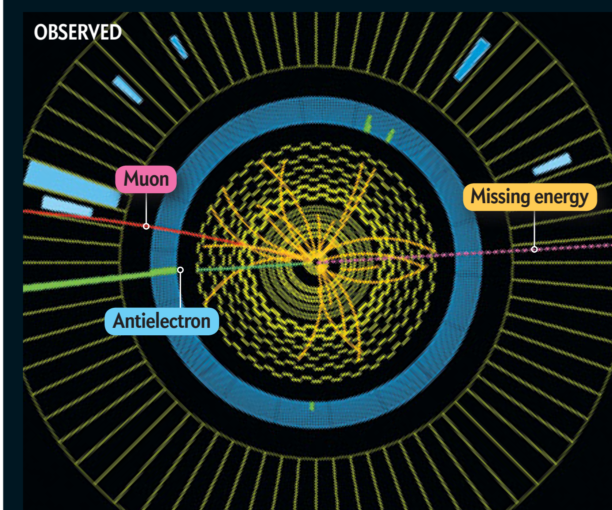




W Bosons

The Higgs can also decay to two *W* bosons, each of which can decay into an electron, antielectron or muon, plus a neutrino or antineutrino. Neutrinos are nearly impossible to detect—they fly out of the detector as if they were never there, taking with them some of the event's energy. Researchers use this missing energy to infer their presence, but the missing energy also prevents them from accurately reconstructing the mass of the original Higgs boson.





researchers could not convince the lab director to grant them a reprieve, and the Tevatron was soon shut down [see "Waiting for the Higgs," by Tim Folger; Scientific American, October 2011]. (This past March these physicists reported a more detailed analysis that showed a bulge centered at 125 GeV, reinforcing the CERN results.)

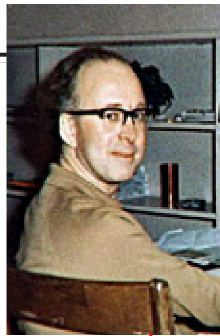
CROSSING THE LINE

By May 2012 the LHC was producing data 15 times faster than the Tevatron had ever achieved, thanks to efforts of physicists and operators led by accelerator director Stephen Myers. This run was a culmination of two decades of work by thousands of ATLAS and CMS physicists who built and now operate the detectors, designed and now manage a computer system that distributes data around the world, created novel hardware and computer software to identify the most interesting collisions, and wrote the algorithms that dig out the most pertinent events from the great morass of data being recorded. They all worked feverishly, anticipating a discovery. So when the researchers opened their data sets in mid-June, they had torrents of events to sift

TIMELINE

Five Decades of the Higgs

This summer's discovery of a Higgs-like particle marks the culmination of a decades-long search. In the years before the Standard Model of particle physics came together, researchers realized that they had no explanation for why particles should have mass. A series of theoretical insights suggested that a new type of field—now called the Higgs field—could slow particles down and give them their inertia. This field should have a particle counterpart, and so the search for the Higgs was on.



August 1964
THE PAPERS
François Englert and Robert Brout publish the first of three papers proposing a particle and mechanism that will come to be named after Peter W. Higgs (*left*), author of the second paper, which is published two weeks later. Gerald Guralnik, Carl Hagen and Tom Kibble publish the third paper in November.

August 1979
GLUON DISCOVERED
Scientists first observe the gluon, the particle responsible for nuclear forces, at the DESY laboratory in Hamburg, Germany. Theorists calculate that gluon fusion will create more Higgs bosons than any other process.

January 1983
***W* BOSON DISCOVERED**
One of the last missing pieces of the Standard Model is uncovered when an experiment at the Super Proton Synchrotron at CERN near Geneva spots *W* bosons for the first time.

July 1989
NEW COLLIDER COMES ONLINE
In an effort to bag bigger quarry, CERN constructs the Large Electron Positron (LEP) collider inside a circular, 27-kilometer-long tunnel.

through. After graduate students and postdocs worked through the night, they anxiously prepared to reveal what had turned up.

It was a hot afternoon on June 15 when CMS physicists began gathering in Room 222 of the CERN filtration plant to hear the young physicists' reports. Soon the room was crowded with hundreds of collaboration members—out of about 3,000 in all—many of them standing or sitting on the floor. Few had slept much the night before. Tension and excitement gripped the room.

The first speaker discussed one possible Higgs decay route, or "channel," into pairs of *W* bosons. A small excess of events appeared in the low-mass region of most interest, but the faint signal generated no great excitement. Then presentations on the rare four-lepton and two-photon decays came one after the other. Now it indeed looked like a Higgs boson was showing up at long last. The signals from the 2012 data were occurring again in the same vicinity—near 125 GeV—that had so tantalized researchers six months earlier. Scientists realized almost immediately that if they were to combine the new data with the 2011 results, chances were good that CMS could claim a Higgs discovery. The crowd cheered at the end of the two key presentations.

Similar kinds of revelations occurred in the ATLAS experiment. Spontaneous celebrations broke out in several groups when they looked at the new data. Yet it took more than a week of long workdays and sleepless nights before these physicists were certain that they could conclude that the chances that these events were the result of random fluctuations were less than one in three million—corresponding to the stringent "five sigma" standard that particle physicists insist on to claim a discovery. Loud clapping and cries of joy greeted the moment of recognition.

By that time word of a discovery had leaked out. Worldwide interest began growing so intense that secrecy was placed at a premium. There were to be no further leaks before the official word was presented, particularly because the exact content of documents under preparation could change. ATLAS members were not supposed to talk about the recent results with CMS physicists, nor vice versa. Individual physicists, however, could not resist discussing the news many had awaited so long. Hushed conversations in the CERN cafeteria and corridors suggested that something big was building up. Pressure to go public swelled.

CERN director Rolf-Dieter Heuer got an early glance at the findings in a June 22 meeting with Gianotti and Joseph Incandela of the University of California, Santa Barbara, Tonelli's successor as CMS spokesperson. Heuer decided that the evidence was strong enough to make public. He immediately informed the CERN Council (its governing body) to keep them abreast of the fast-moving developments. Heuer then decided to hold a joint seminar at CERN on July 4, timed to coincide with the opening of the 36th International Conference on High Energy Physics in Melbourne, Australia, followed by a CERN press conference.

The night before the seminar, hundreds of physicists dozed fitfully in the hallways outside the locked main auditorium, desperately hoping to get one of the unreserved seats remaining inside. Myers, Evans and four prior CERN directors who had been heavily involved with the LHC since its conception were seated in the front row. Having just flown to Geneva, Peter Higgs walked in to warm, sustained applause and sat down next to Englert.

Incandela and then Gianotti showed blizzards of slides about the new data and results, mostly covering the 2012 measurements. As in December, graphs of two-photon data revealed striking peaks jutting out at 125 to 126 GeV. And this time around, the experiments had more than a dozen extra events in which a heavy particle had exploded into four charged leptons at 125 GeV. Subtle peaks had begun to form in that channel, too.

That clinched it. Combining this result with the two-photon one, CMS and ATLAS independently concluded that the chances that the apparition was a fluke, due to random fluctuations, were less than one in three million. It had to be real. When the camera panned to Higgs, he could be seen pulling out a handkerchief to wipe his eyes.

"I think we have it," exulted Heuer, wrapping up the seminar

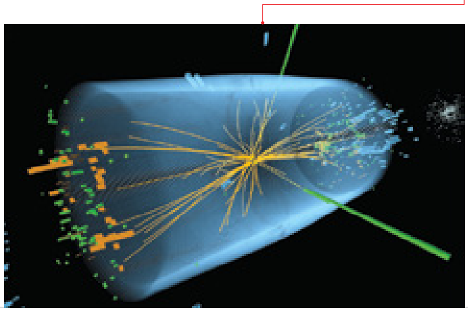
COURTESY OF CERN (*facilities and collision events*); AP IMAGES (*Higgs*)

November 2, 2000
THE END OF AN ERA
The LEP collider closes so that construction may begin on CERN's Large Hadron Collider (LHC), the machine that will eventually find the Higgs.

September 10, 2008
ALL SYSTEMS GO
The first proton beams shoot around the newly finished LHC.

September 19, 2008
DISASTER STRIKES
After an electrical splice between two magnets warms and melts, a powerful spark punctures a magnet vessel and releases tons of liquid helium. More than 50 magnets rip from their mounts or are otherwise damaged.

September 2000
LAST PUSH FOR THE HIGGS
Scientists at LEP detect hints of the Higgs boson just as the machine is scheduled to be permanently shut down. Administrators offer a six-week reprieve and push the machine past its design energy but for naught. We now know the weak signal was not the Higgs after all: it was at the wrong mass.



July 4, 2012
HIGGS-LIKE PARTICLE FOUND
CERN scientists announce that they have discovered a Higgs-like particle at 125 GeV.

—Compiled by Marissa Fessenden

to sustained applause. "We have a discovery," he went on, guardedly using the word at last. "We have observed a new particle consistent with a Higgs boson."

A NEW ERA IN PHYSICS?

FEW PHYSICISTS NOW DOUBT that a heavy new particle has turned up. But exactly what sort of particle might it be? CERN physicists spoke cautiously on this question, calling it a "Higgs-like boson" and insisting that more data were needed to pin down its properties. CERN has not yet proved conclusively that the new particle has the property of zero "spin," as required by the Standard Model—although a comparison with the latest Tevatron data (released on July 2 in an obvious attempt to share the limelight) suggested this was true. The ATLAS and CMS experiments are also picking up more two-photon events than expected. Could something be amiss? Or is this surfeit hinting at intriguing new physics?

Attention, both experimental and theoretical, is currently focused on resolving whether the new particle is indeed "the" Higgs boson predicted by the Standard Model or not. That question can be resolved by taking more data and accurately measuring how this new particle decays into other particles. The official publications submitted in late July included further decay channels that do not contradict the Standard Model. CMS still reported a five-sigma discovery, while the ATLAS results had grown stronger. And early analysis of the combined LHC and Tevatron data by CERN theorists John Ellis and Tevong You indicated that the new particle, as they put it, "does indeed walk and quack very much like a Higgs boson."

The new particle's connection with a pair of high-energy photons has stimulated intrigue. Because the Higgs field imbues elementary particles with mass, it should interact more strongly with heavier particles. Photons have no mass, so the Higgs boson produces them via a mechanism involving other, massive particles. Additional heavy particles (which are required by supersymmetry and other theories) could enhance the process—as appears to be happening, based on early data. If the tendency holds up, it will strongly suggest physics beyond that described by the Standard Model [see "The Coming Revolutions in Particle Physics," by Chris Quigg; SCIENTIFIC AMERICAN, February 2008].

The epochal discovery of this particle marks the end of a long era in particle physics and the beginning of an exciting new phase studying phenomena at the TeV energy scale. After decades in the doldrums, the discipline is energized once again by the heady intercourse of theory and experiment. Questions abound that may find answers from further research on this fascinating particle or its potential partners. Does it play a role in the inflation mechanism considered the force driving the big bang origins of the universe? Does it interact with dark matter particles thought to inhabit the cosmos? And what higher-energy mechanism or process, if any, shields the fragile vacuum from instabilities that may threaten our existence?

Although we celebrate the triumph of the Standard Model, such a lightweight Higgs boson should be extremely sensitive to physics lying beyond it. The particle opens up a fabulous new laboratory for further experimentation. Are its properties exactly as predicted? The apparent discrepancies in the early data could be random fluctuations that disappear in months to come. Or perhaps they are offering subtle hints of intriguing new physics. SA

MORE TO EXPLORE

The Mysteries of Mass. Gordon Kane in *Scientific American,* Vol. 293, No. 1, pages 30–38; July 2005.

The Coming Revolutions in Particle Physics. Chris Quigg in *Scientific American,* Vol. 298, No. 2, pages 38–45; February 2008.

The Discovery Machine. Graham P. Collins in *Scientific American,* Vol. 298, No. 2, pages 31–37; February 2008.

The ATLAS experiment: **http://atlas.ch**

The CMS experiment: **http://cms.cern.ch**

SCIENTIFIC AMERICAN ONLINE
Watch a video explainer on the Higgs boson at **ScientificAmerican.com/oct2012/higgs**

SA IMAGES

ENERGY

KINETIC KITE

An airborne wind turbine turns sea breezes into electricity

By David Biello

The powerful thrust of ocean-spawned winds can zip a kite surfer across the sea's surface at up to 55 miles per hour. Engineers are now trying to harvest the power in that wind to generate electricity. The Wing 7 airborne wind turbine pictured here is a prototype of a leading contender for the job. The autonomous, lightweight device is tethered to land or to a floating platform; when wind speeds pick up, four rotors fly it up above 820 feet in a circle perpendicular to the wind. As the air rushes across the carbon-fiber wing, the rotors generate electricity by spinning permanent magnets. "The rotors are both propellers and turbines," notes mechanical engineer Corwin Hardham, CEO and co-founder of Makani Power, which created the Wing 7. An onboard computer makes constant adjustments.

The idea of generating power with kites, to avoid the fickleness of winds closer to the earth, is centuries old; modern iterations—including schemes for harvesting energy by flying into jet streams—date back to at least the 1970s. Makani intends to meet that challenge by designing its kite to work over the ocean, where the wind blows fairly constantly, and to cover a wide expanse of sky in its circular flight. Even relatively light winds that fail to stir traditional turbines can speed the light, tethered aircraft at more than 100 miles per hour and allow it to generate power.

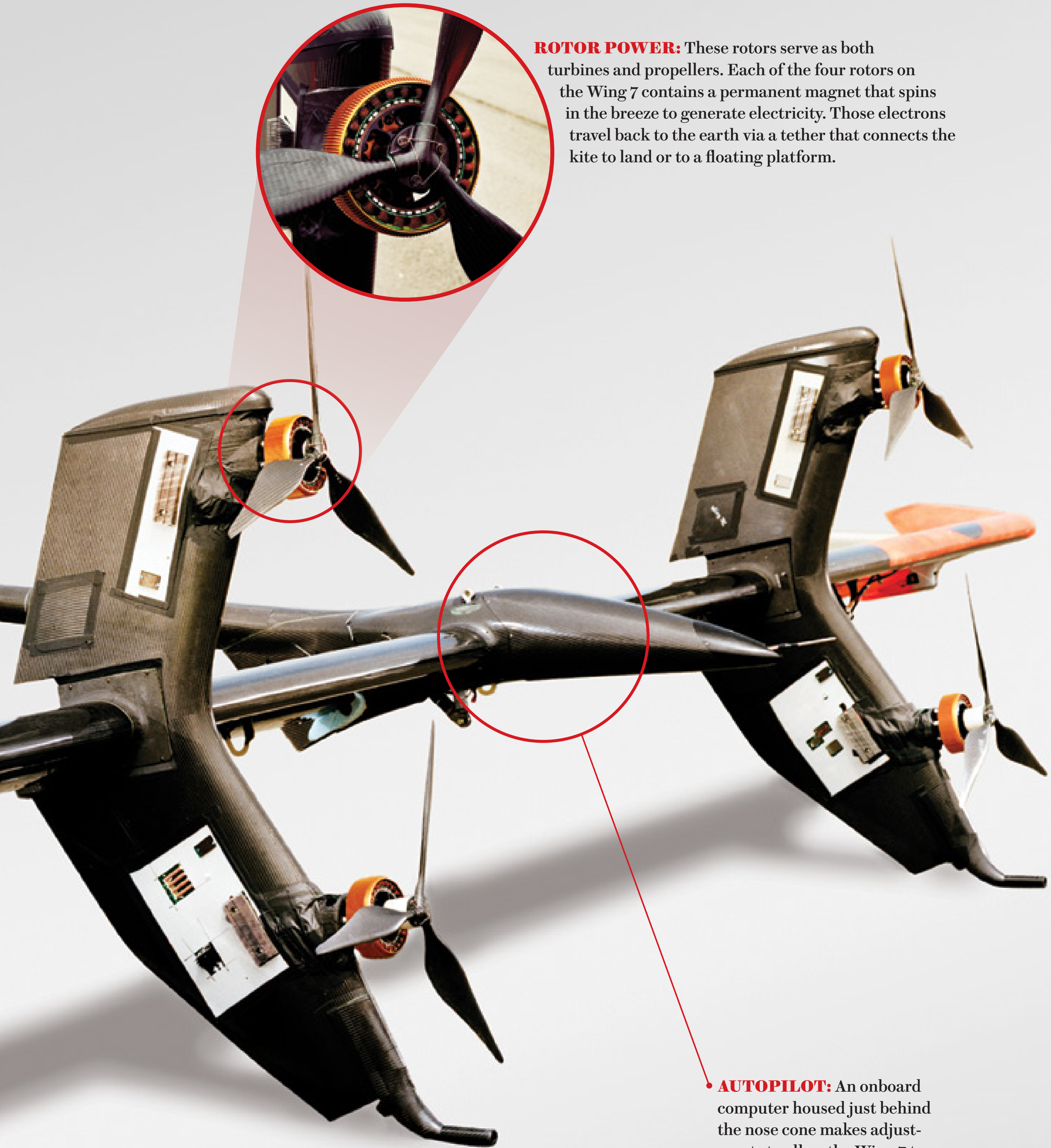
The possibility of capturing some fraction of the power in winds out of reach of even the tallest ground-based turbines has

drawn ongoing financial support from Google, the U.S. Department of Energy's Advanced Research Projects Agency–Energy and others. Right now the Wing 7 can generate 30 kilowatts of power—slightly less than the typical automobile engine. Makani plans to develop and deploy its first 600-kilowatt device—akin to a small ground-based wind turbine—by 2016.

David Biello *is an associate editor at* Scientific American.

SCIENTIFIC AMERICAN ONLINE
For a video of the kite in flight, see ScientificAmerican.com/oct2012/kite-turbine

Photograph by Jake Stangel



ROTOR POWER: These rotors serve as both turbines and propellers. Each of the four rotors on the Wing 7 contains a permanent magnet that spins in the breeze to generate electricity. Those electrons travel back to the earth via a tether that connects the kite to land or to a floating platform.

AUTOPILOT: An onboard computer housed just behind the nose cone makes adjustments to allow the Wing 7 to generate the most power in flight. Carbon fiber throughout the kite makes it light but strong: the 120-pound device can pull more than three tons. “It can pull your car away,” says Makani Power’s Corwin Hardham.

We can learn a lot from psychopaths. Certain aspects of their personalities and intellect are often hallmarks of success

By Kevin Dutton

PSYCHOLOGY

THE WISDOM OF PSYCHOPATHS

TRAITS THAT ARE COMMON AMONG PSYCHOPATHIC SERIAL KILLERS—A GRANDIOSE SENSE OF self-worth, persuasiveness, superficial charm, ruthlessness, lack of remorse and the manipulation of others—are also shared by politicians and world leaders. Individuals, in other words, running not from the police. But for office. Such a profile allows those who present with these traits to do what they like when they like, completely unfazed by the social, moral or legal consequences of their actions.

Adapted from The Wisdom of Psychopaths, *by Kevin Dutton, by arrangement with Scientific American/Farrar, Straus and Giroux, LLC (US), Doubleday Canada (Canada), Heinemann (UK), Record (Brazil), DTV (Germany), De Bezige Bij (Netherlands), NHK (Japan), Miraebook (Korea) and Lua de Papel (Portugal).*

If you are born under the right star, for example, and have power over the human mind as the moon over the sea, you might order the genocide of 100,000 Kurds and shuffle to the gallows with such arcane recalcitrance as to elicit, from even your harshest detractors, perverse, unspoken deference.

"Do not be afraid, doctor," said Saddam Hussein on the scaffold, moments before his execution. "This is for men."

If you are violent and cunning, like the real-life "Hannibal Lecter" Robert Maudsley, you might take a fellow inmate hostage, smash his skull in and sample his brains with a spoon as nonchalantly as if you were downing a soft-boiled egg. (Maudsley, by the way, has been cooped up in solitary confinement for the past 30 years, in a bul-

Illustration by Tim Bower

letproof cage in the basement of Wakefield Prison in England.)

Or if you are a brilliant neurosurgeon, ruthlessly cool and focused under pressure, you might, like the man I'll call Dr. Geraghty, try your luck on a completely different playing field: at the remote outposts of 21st-century medicine, where risk blows in on 100-mile-per-hour winds and the oxygen of deliberation is thin. "I have no compassion for those whom I operate on," he told me. "That is a luxury I simply cannot afford. In the theater I am reborn: as a cold, heartless machine, totally at one with scalpel, drill and saw. When you're cutting loose and cheating death high above the snowline of the brain, feelings aren't fit for purpose. Emotion is entropy—and seriously bad for business. I've hunted it down to extinction over the years."

Geraghty is one of the U.K.'s top neurosurgeons—and although, on one level, his words send a chill down the spine, on another they make perfect sense. Deep in the ghettoes of some of the brain's most dangerous neighborhoods, the psychopath is glimpsed as a lone and merciless predator, a solitary species of transient, deadly allure. No sooner is the word out than images of serial killers, rapists and mad, reclusive bombers come stalking down the sidewalks of our minds.

But what if I were to paint you a different picture? What if I were to tell you that the arsonist who burns your house down might also, in a parallel universe, be the hero most likely to brave the flaming timbers of a crumbling, blazing building to seek out, and drag out, your loved ones? Or that the kid with a knife in the shadows at the back of the movie theater might well, in years to come, be wielding a rather different kind of knife at the back of a rather different kind of theater?

Claims like these are admittedly hard to believe. But they're true. Psychopaths are fearless, confident, charismatic, ruthless and focused. Yet, contrary to popular belief, they are not necessarily violent. Far from its being an open-and-shut case—you're either a psychopath or you're not—there are, instead, inner and outer zones of the disorder: a bit like the fare zones on a subway map. There is a spectrum of psychopathy along which each of us has our place, with only a small minority of A-listers resident in the "inner city."

Think of psychopathic traits as the dials on a studio mixing deck. If you turn all of them to max, you'll have a soundtrack that's no use to anyone. But if the soundtrack is graded, and some are up higher than others—such as fearlessness, focus, lack of empathy and mental toughness, for example—you may well have a surgeon who's a cut above the rest.

Of course, surgery is just one instance where psychopathic "talent" may prove advantageous. There are others. In 2009, for instance, I decided to perform my own research to determine whether, if psychopaths were really better at decoding vulnerability (as had been found in some studies), there could be applications. There had to be ways in which, rather than being a drain on society, this ability actually conferred some benefit. And there had to be ways to study it.

Enlightenment dawned when I met a friend at the airport. We all get a bit paranoid going through customs, I mused. Even when we're perfectly innocent. But imagine what it would feel like if we did have something to hide—and if an airport security officer were particularly good at picking up on that feeling?

Kevin Dutton is a research psychologist at the Calleva Research Center for Evolution and Human Sciences at Magdalen College, University of Oxford.

To find out, I decided to conduct an experiment. Thirty undergraduate students took part: half of them high on the Self-Report Psychopathy Scale, and half of them low. There were also five "associates." The students' job was easy. They had to sit in a classroom and observe the associates' movements as they entered through one door and exited through another, traversing, en route, a small, elevated stage. But there was a catch. They also had to note who was "guilty": Which one of the five was concealing a scarlet handkerchief?

To raise the stakes and give the observers something to "go on," the associate with the handkerchief was handed £100. If the jury decided that they were the guilty party—if, when the votes were counted, they came out on top—then they had to hand it back. If, on the other hand, they got away with it, and the finger of suspicion fell heavier on one of the others, they would, in contrast, stand to be rewarded. They would, instead, get to keep the £100.

Which of the students would make the better "customs officers"? Would the psychopaths' predatory instincts prove reliable? Or would their nose for vulnerability let them down?

More than 70 percent of those who scored high on the Self-Report Psychopathy Scale correctly picked out the handkerchief-smuggling associate, compared with just 30 percent of the low scorers. Zeroing in on weakness may well be part of a serial killer's tool kit. But it may also come in handy at the airport.

TROLLEYOLOGY

JOSHUA GREENE, a psychologist at Harvard University, has observed how psychopaths unscramble moral dilemmas. As I described in my 2011 book, *Split-Second Persuasion,* he has stumbled on something interesting. Far from being uniform, empathy is schizophrenic. There are two distinct varieties: hot and cold.

Consider, for example, the following conundrum (Case 1), first proposed by the late philosopher Philippa Foot:

A railway trolley is hurtling down a track. In its path are five people who are trapped on the line and cannot escape. Fortunately, you can flip a switch that will divert the trolley down a fork in the track away from the five people—but at a price. There is another person trapped down that fork, and the trolley will kill him or her instead. Should you hit the switch?

Most of us experience little difficulty when deciding what to do in this situation. Although the prospect of flipping the switch isn't exactly a nice one, the utilitarian option—killing just the one person instead of five—represents the "least worst choice." Right?

Now consider the following variation (Case 2), proposed by philosopher Judith Jarvis Thomson:

As before, a railway trolley is speeding out of control down a track toward five people. But this time you are standing behind a very large stranger on a footbridge above the tracks. The only way to save the five people is to heave the stranger over. He will fall to a certain death. But his considerable girth will block the trolley, saving five lives. Question: Should you push him?

SOURCE: PAUL WILLIAMS

Here you might say we're faced with a "real" dilemma. Although the score in lives is precisely the same as in the first example (five to one), playing the game makes us a little more circumspect and jittery. But why?

Greene believes he has the answer. It has to do with different climatic regions in the brain.

Case 1, he proposes, is what we might call an impersonal moral dilemma and involves those areas of the brain, the prefrontal cortex and posterior parietal cortex (in particular, the anterior paracingulate cortex, the temporal pole and the superior temporal sulcus), principally implicated in our objective experience of cold empathy: in reasoning and rational thought.

Case 2, on the other hand, is what we might call a personal moral dilemma. It hammers on the door of the brain's emotion center, known as the amygdala—the circuit of hot empathy.

Just like most normal members of the population, psychopaths make pretty short work of the dilemma presented in Case 1. Yet—and this is where the plot thickens—quite unlike normal people, they also make pretty short work of Case 2. Psychopaths, without batting an eye, are perfectly happy to chuck the fat guy over the side.

To compound matters further, this difference in behavior is mirrored, rather distinctly, in the brain. The pattern of neural activation in both psychopaths and normal people is well matched on the presentation of impersonal moral dilemmas—but dramatically diverges when things get a bit more personal.

Imagine that I were to pop you into a functional MRI machine and then present you with the two dilemmas. What would I observe as you went about negotiating their moral minefields? Just around the time that the nature of the dilemma crossed the border from impersonal to personal, I would see your amygdala and related brain circuits—your medial orbitofrontal cortex, for example—light up like a pinball machine. I would witness the moment, in other words, that emotion puts its money in the slot.

But in a psychopath, I would see only darkness. The cavernous neural casino would be boarded up and derelict—the crossing from impersonal to personal would pass without any incident.

THE PSYCHOPATH MIX

THE QUESTION of what it takes to succeed in a given profession, to deliver the goods and get the job done, is not all that difficult when it comes down to it. Alongside the dedicated skill set necessary to perform one's specific duties—in law, in business, in whatever field of endeavor you care to mention—exists a selection of traits that code for high achievement.

In 2005 Belinda Board and Katarina Fritzon, then at the University of Surrey in England, conducted a survey to find out precisely what it was that made business leaders tick. What, they wanted to know, were the key facets of personality that separated those who turn left when boarding an airplane from those who turn right?

Board and Fritzon took three groups—business managers, psychiatric patients and hospitalized criminals (those who were psychopathic and those suffering from other psychiatric illnesses)—and compared how they fared on a psychological profiling test.

Their analysis revealed that a number of psychopathic attributes were actually more common in business leaders than in so-called disturbed criminals—attributes such as superficial charm, egocentricity, persuasiveness, lack of empathy, independence, and focus. The main difference between the groups was in the more "antisocial" aspects of the syndrome: the criminals' lawbreaking, physical aggression and impulsivity dials (to return to our analogy of earlier) were cranked up higher.

Other studies seem to confirm the "mixing deck" picture: that the border between functional and dysfunctional psychopathy depends not on the presence of psychopathic attributes per se but rather on their levels and the way they are combined. Mehmet Mahmut and his colleagues at Macquarie University in Sydney have recently shown that patterns of brain dysfunction (specifically, patterns in orbitofrontal cortex functioning—the area of the brain that regulates the input of the emotions in decision making) observed in both criminal and noncriminal psychopaths, exhibit dimensional rather than discrete differences. This, Mahmut suggests, means that the two groups should not be viewed as qualitatively distinct populations but rather as occupying different positions on the same continuum.

Think of psychopathic traits as the dials on a studio mixing deck.

In a similar (if less high-tech) vein, I asked a class of first-year undergraduates to imagine they were managers in a job placement company. "Ruthless, fearless, charming, amoral and focused," I told them. "Suppose you had a client with that kind of profile. To which line of work do you think they might be suited?"

Their answers couldn't have been more insightful. CEO, spy, surgeon, politician, the military … they all popped up in the mix. Amongst serial killer, assassin and bank robber.

"Intellectual ability on its own is just an elegant way of finishing second," one successful CEO told me. "Remember, they don't call it a greasy pole for nothing. The road to the top is hard. But it's easier to climb if you lever yourself up on others. Easier still if they think something's in it for them."

Jon Moulton, one of London's most successful venture capitalists, agrees. In a recent interview with the *Financial Times,* he lists determination, curiosity and insensitivity as his three most valuable character traits.

No prizes for guessing the first two. But insensitivity? The great thing about insensitivity, Moulton explains, is that "it lets you sleep when others can't." ■

MORE TO EXPLORE

What "Psychopath" Means. Scott O. Lilienfeld and Hal Arkowitz in *Scientific American Mind,* Vol. 18, No. 6, pages 80–81; December 2007/January 2008.

Inside the Mind of a Psychopath. Kent A. Kiehl and Joshua W. Buckholtz in *Scientific American Mind,* Vol. 21, No. 4, pages 22–29; September/October 2010.

How to Act Like a Psychopath without Really Trying [Excerpt]. John Whitfield. Published online December 9, 2011, at **www.ScientificAmerican.com/article.cfm?id=how-to-act-like-a-psychopath**

SCIENTIFIC AMERICAN ONLINE
Read an interview with a psychopath and assess your own psychopathic traits at **ScientificAmerican.com/oct2012/psychopath**

BIOCHEMISTRY

Journey to the Genetic Interior

What was once known as junk DNA turns out to hold hidden treasures, says computational biologist Ewan Birney

Interview by Stephen S. Hall

IN THE 1970S, WHEN BIOLOGISTS FIRST GLIMPSED THE LANDSCAPE OF HUMAN genes, they saw that the small pieces of DNA that coded for proteins (known as exons) seemed to float like bits of wood in a sea of genetic gibberish. What on earth were those billions of other letters of DNA there for? No less a molecular luminary than Francis Crick, co-discoverer of DNA's double-helical structure, suspected it was "little better than junk."

IN BRIEF

WHO
EWAN BIRNEY

VOCATION/AVOCATION
"Cat herder in chief" of the ENCODE consortium of 400 geneticists from around the world

WHERE
European Bioinformatics Institute, Cambridge, England

RESEARCH FOCUS
Creating an encyclopedia detailing what the most mysterious parts of the human genome do

BIG PICTURE
"I get this strong feeling that previously I was ignorant of my own ignorance, and now I understand my ignorance."

The phrase "junk DNA" has haunted human genetics ever since. In 2000, when scientists of the Human Genome Project presented the first rough draft of the sequence of bases, or code letters, in human DNA, the initial results appeared to confirm that the vast majority of the sequence—perhaps 97 percent of its 3.2 billion bases—had no apparent function. The "Book of Life," in other words, looked like a heavily padded text.

But beginning roughly at that same time, a consortium of dozens of international laboratories embarked on a massive, unglamorous and largely unnoticed project to annotate what one biologist has called the "humble, unpretentious non-gene" parts of the human genome. Known as the Encyclopedia of DNA Elements (ENCODE for short), the project required scientists, in essence, to crawl along the length of the double helix as they attempted to identify anything with a biological purpose. In 2007 the group published a preliminary report hinting that, like the stuff all of us park in the attic, there were indeed treasures aplenty amid the so-called junk.

Now, in a series of papers published in September in *Nature* (*Scientific American* is part of Nature Publishing Group) and elsewhere, the ENCODE group has produced a stunning inventory of previously hidden switches, signals and sign-

Photograph by John Spinks

posts embedded like runes throughout the entire length of human DNA. In the process, the ENCODE project is reinventing the vocabulary with which biologists study, discuss and understand human inheritance and disease.

Ewan Birney, 39, of the European Bioinformatics Institute in Cambridge, England, led the analysis by the more than 400 ENCODE scientists who annotated the genome. He recently spoke with Scientific American about the major findings. Excerpts follow.

Scientific American: The ENCODE project has revealed a landscape that is absolutely teeming with important genetic elements—a landscape that used to be dismissed as "junk DNA." Were our old views of how the genome is organized too simplistic?

BIRNEY: People always knew there was more there than protein-coding genes. It was always clear that there was regulation. What we didn't know was just quite how extensive this was.

Just to give you a sense here, about 1.2 percent of the bases are in protein-coding exons. And people speculated that "maybe there's the same amount again involved in regulation or maybe a little bit more." But even if we take quite a conservative view from our ENCODE data, we end up with something like 8 to 9 percent of the bases of the genome involved in doing something like regulation.

Thus, much more of the genome is devoted to regulating genes than to the protein-coding genes themselves?

And that 9 percent can't be the whole story. The most aggressive view of the amount we've sampled is 50 percent. So certainly it's going to go above 9 percent, and one could easily argue for something like 20 percent. That's not an unfeasible number.

Should we be retiring the phrase "junk DNA" now?

Yes, I really think this phrase does need to be totally expunged from the lexicon. It was a slightly throwaway phrase to describe very interesting phenomena that were discovered in the 1970s. I am now convinced that it's just not a very useful way of describing what's going on.

What is one surprise you have had from the "junk"?

There has been a lot of debate, inside of ENCODE and outside of the project, about whether or not the results from our experiments describe something that is really going on in nature. And then there was a rather more philosophical question, which is whether it matters. In other words, these things may biochemically occur, but evolution, as it were, or our body doesn't actually care.

That debate has been running since 2003. And then work by ourselves, but also work outside of the consortium, has made it much clearer that the evolutionary rules for regulatory elements are different from those for protein-coding elements. Basically the regulatory elements turn over a lot faster. So whereas if you find a particular protein-coding gene in a human, you're going to find nearly the same gene in a mouse most of the time, and that rule just doesn't work for regulatory elements.

In other words, there is more complex regulation of genes, and more rapid evolution of these regulatory elements, in humans?

Absolutely.

That's a rather different way of thinking about genes—and evolution.

I get this strong feeling that previously I was ignorant of my own ignorance, and now I understand my ignorance. It's slightly depressing as you realize how ignorant you are. But this is progress. The first step in understanding these things is having a list of things that one has to understand, and that's what we've got here.

Earlier studies suggested that only, say, 3 to 15 percent of the genome had functional significance—that is, actually did something, whether coding for proteins, regulating how the genes worked or doing something else. Am I right that the ENCODE data imply, instead, that as much as 80 percent of the genome may be functional?

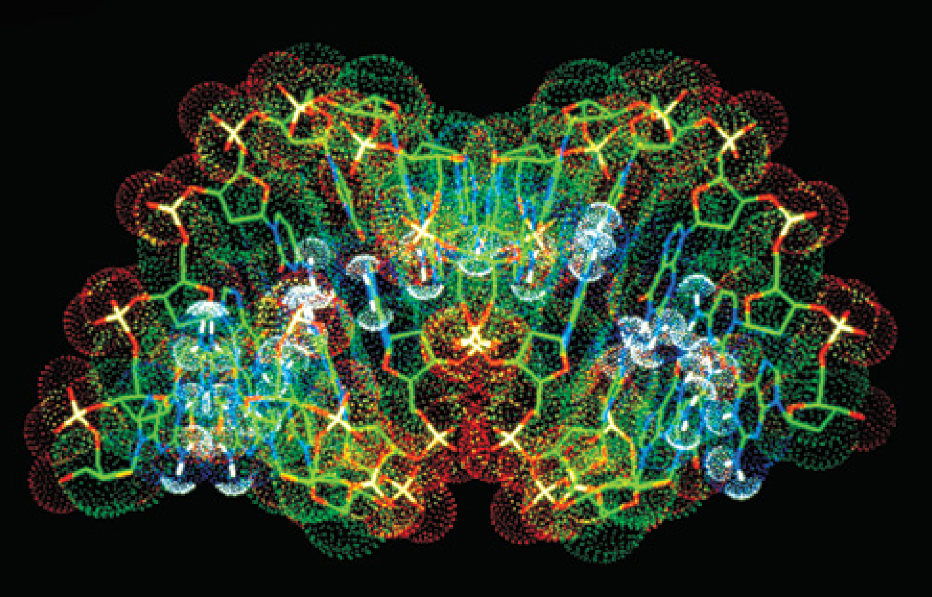
One can use the ENCODE data and come up with a number between 9 and 80 percent, which is obviously a very big range. What's going on there? Just to step back, the DNA inside of our cells is wrapped around various proteins, most of them histones, which generally work to keep everything kind of safe and happy. But there are other types of proteins called transcription factors, and they have specific interactions with DNA. A transcription factor will bind only at 1,000 places, or maybe the biggest bind is at 50,000 specific places across the genome. And so, when we talk about this 9 percent, we're really talking about these very specific transcription-factor-to-DNA contacts.

On the other hand, the copying of DNA into RNA seems to happen all the time—about 80 percent of the genome is actually transcribed. And there is still a raging debate about whether this large amount of transcription is a background process that's not terribly important or whether the RNA that is being made actually does something that we don't yet know about.

Personally, I think everything that is being transcribed is worth further exploration, and that's one of the tasks that we will have to tackle in the future.

There is a widespread perception that the attempts to identify common genetic variants related to human disease through so-called genome-wide association studies, or GWAS, have not revealed that much. Indeed, the ENCODE results now show that about 75 percent of the DNA regions that the GWAS have previously linked to disease lie nowhere near protein-coding genes. In terms of disease, have we been wrong to focus on mutations in protein-coding DNA?

Genome-wide association studies are very interesting, but they are not some magic bullet for medicine. The GWAS situation had everyone sort of scratching their heads. But when we put these genetic associations alongside the ENCODE data, we saw that although the loci are



ENIGMA: Researchers have found greater complexity in human DNA than this "simple" model would suggest.

not close to a protein-coding gene, they really are close to one of these new elements that we're discovering. That's been a lovely thing. In fact, when I first saw it, it was a slightly too-good-to-be-true moment. And we spent a long time double-checking everything.

How does that discovery help us understand disease?
It's like opening a door. Think about all the different ways you can study a particular disease, such as Crohn's: Should we look at immune system cells in the gut? Or should we look at the neurons that fire to the gut? Or should we be looking at the stomach and how it does something else?

All those are options. Now suddenly ENCODE is letting you examine those options and say, "Well, I really think you should start by looking at this part of the immune system—the helper T cells—first." And we can do that for a very, very big set of diseases. That's really exciting.

Now that we are retiring the phrase "junk DNA," is there another, better metaphor that might explain the emerging view of the genetic landscape?
What it feels like is genuinely a jungle—a completely dense jungle of stuff that you have to work your way through. You're trying to hack your way to a certain position. And you're really not sure where you are, you know? It's quite easy to feel lost in there.

Over the past 20 years the public has been repeatedly told that these big genomic projects—starting with the Human Genome Project and going on through various other projects—were going to explain everything we needed to know about the "book of life." Is ENCODE simply the latest in this sequence?
I think that each time we always said, "These are foundations. You build on them." Nobody said, "Look, the human genome bases, that's it. It's all done and dusted—we've just got a bit of code breaking to do here." Everybody said, "We're going to be studying this for 50 years, 100 years. But this is the foundation that we start on." I do get the feeling that the ENCODE project is the next layer in that foundational resource for other people to stand on top of and look further. The biggest change here is in our list of known unknowns. And I think people should understand that although finding out how much you don't know can feel regressive and frustrating, identifying the gaps is really good.

Ten years ago we didn't know what we didn't know. There is no doubt that ENCODE poses many, many, many more questions than it directly answers. At the same time, for Crohn's disease, say, and lots of other things, there are some effectively quick wins and low-hanging fruit—at least for researchers—where you start to say to people, "Oh my gosh, have you looked there?"

It's just one more step. It's an important step, but nowhere near the end, I'm afraid.

You sometimes refer to yourself as ENCODE's "cat herder in chief." How many people were involved in the consortium, and what was it like coordinating such a massive effort?
This is very much a different way of doing science. I am only one of 400 investigators, and I am the person who is charged to make sure that the analysis was delivered and that it all worked out. But I had to draw on the talents of many, many people.

So I'm more like the cat herder, the conductor, necessarily, than someone whose brain can absorb all of this. It comes back to that sense that it's a bit of a jungle out there.

Well, you deserve a lot of credit. It's more than just cats. They're pretty opinionated cats.
Yeah, they are. What scientists are not are dogs. Dogs naturally run in packs. Cats? No. And I think that sums up the normal scientific phenotype. And so you have to cajole these people sometimes into sort of taking the same direction.

Do you see a point where all this complex information will resolve into a simpler message about human inheritance and human disease? Or do we have to accept the fact that complexity is, as it were, in our DNA?
We are complex creatures. We should expect that it's complex out there. But I think we should be happy about that and maybe even proud about it. SA

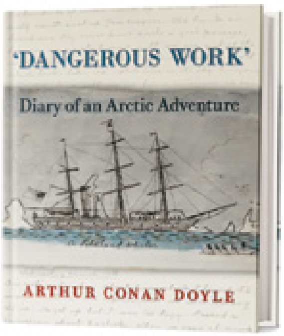
Stephen S. Hall *has written about science for the* Atlantic, New York Times Magazine, New Yorker *and many other magazines.*

MORE TO EXPLORE

The ENCODE project: Encyclopedia of DNA Elements: www.genome.gov/10005107

SCIENTIFIC AMERICAN ONLINE
Discover more about DNA at ScientificAmerican.com/oct2012/genes

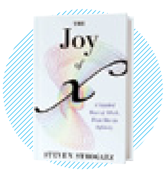
BOOKS



"Dangerous Work": Diary of an Arctic Adventure

by Arthur Conan Doyle. University of Chicago Press, 2012 ($35)

Long before he wrote the Sherlock Holmes detective novels, Conan Doyle interrupted his medical school studies to serve in 1880 as a ship's surgeon onboard a whaler bound for the Arctic. In his diary (*above*), reproduced from the original and accompanied by commentary from two Conan Doyle scholars, the author describes scrambling across ice sheets in search of seals to club and whales to spear, and he sketches pictures of other journey highlights. Memories of this voyage, he later wrote, stayed with him for the rest of his life.



The Joy of X

by Steven Strogatz. Houghton Mifflin Harcourt, 2012 ($27)

Strogatz, an applied mathematician at Cornell University and author of *Sync,* has compiled his immensely popular series of *New York Times* columns and added new material. *The Joy of X*'s six parts, each divided into several short chapters, move from number basics through algebra, geometry, calculus and statistics to the frontiers of math, where conjectures about prime numbers are still floating around unsolved. The goal is a second chance at learning the math that might have passed you by—this time from an adult perspective. The tone is light and conversational, with delightful narratives about lonely numbers and the Tony Soprano psyche of math itself—outwardly tough but inwardly wracked with insecurity. The easily digestible chapters include plenty of helpful examples and illustrations. You'll never forget the Pythagorean theorem again!

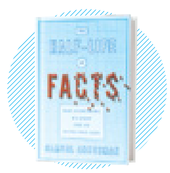
—*Evelyn Lamb*

Mirror Earth: The Search for Our Planet's Twin

by Michael D. Lemonick. Walker & Company, 2012 ($26)

Scientists hunting for planets outside our solar system may be just months away from discovering Earth's twin—a rocky planet like our own, spinning around a star at the right distance to sustain life. In this book, Lemonick, a science writer, spotlights "Exoplaneteer Rock Stars," the scientists who detect planets by marking the telltale wobbles and flickers of the stars that they orbit. He also captures the fascinating lead up to the Kepler mission, which has discovered hundreds of possible worlds.

—*Marissa Fessenden*



The Half-Life of Facts: Why Everything We Know Has an Expiration Date

by Samuel Arbesman. Current, 2012 ($25.95)

Many medical schools tell their students that half of what they've been taught will be wrong within five years—the teachers just don't know which half. Arbesman, a Harvard University–affiliated practitioner of scientometrics—which looks at how we know what we know—sets out to make readers more comfortable with changes in scientific knowledge, from the status of Pluto to the age at which women should get mammograms. Facts change in a regular, predictable manner and obey mathematical rules, he argues: "Once we recognize this, we'll be ready to live in the rapidly changing world around us."

ALSO NOTABLE

EVENT

Flight of the Butterflies. Opens October 1 in Imax theaters. This 3-D documentary tells the story of Fred Urquhart, the late founder of Monarch Watch and one of the first researchers to discover where the butterflies overwinter in Mexico. The documentary follows monarchs as they migrate from Mexico to Canada and back again.

COMMENT AT ScientificAmerican.com/oct2012

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His book *The Believing Brain* is now out in paperback. Follow him on Twitter @michaelshermer

Politically Irrational

Subliminal influences guide our voting preferences

With the 2012 presidential election looming on the horizon in November, consider these two crucial questions: Who looks more competent, Barack Obama or Mitt Romney? Who has the deepest and most resonant voice? Maybe your answer is, "Who cares? I vote for candidates based on their policies and positions, not on how they look and sound!" If so, that very likely is your rational brain justifying an earlier choice that your emotional brain made based on these seemingly shallow criteria.

Before the election, I urge you to read Leonard Mlodinow's new book, *Subliminal: How Your Unconscious Mind Rules Your Behavior* (Pantheon). You will gain such insights as that higher-pitched voices are judged by subjects as more nervous, less truthful and less empathetic than speakers with lower-pitched voices and that speaking a little faster and louder, with fewer pauses and greater variation in volume, leads people to judge someone to be energetic, intelligent and knowledgeable. Looks matter even more. One study presented subjects with campaign flyers featuring black-and-white photographs of models posing as Democrats or Republicans in fictional congressional races; half looked able and competent, whereas the other half did not, as rated by volunteers before the experiment. The flyers included the candidate's name, party affiliation, education, occupation, political experience and three position statements. To control for party preference, half the subjects were shown the more suitable-looking candidate as a Democrat, and the other half saw him as a Republican. Results: 59 percent of the vote went to the candidate with the more capable appearance regardless of other qualifications. A similar study in a mock election resulted in a 12-percentage-point advantage for the more authoritative-looking politician.

To test these effects in real elections, Princeton University psychologist Alexander Todorov and his colleagues had volunteers rate for "competence" black-and-white head shots of all the candidates in 600 contests for the U.S. House of Representatives and 95 races for the Senate from 2000, 2002 and 2004. Results: candidates rated as more competent won 67 percent of the House races and 72 percent of the Senate ones. In a follow-up study published in 2007 the psychologists conducted the face-evaluation process *before* the 2006 elections, predicting the winners in 72 percent of Senate runs and 69 percent of gubernatorial competitions based on the candidates' appearances alone.

These data—and others—confirm what was perceived the night of September 26, 1960, during the first televised presidential debate between John F. Kennedy and Richard M. Nixon. Well rested and tan from campaigning in California, Kennedy was radiant, like an "athlete come to receive his wreath of laurel," journalist Howard K. Smith noted. In contrast, Nixon had been campaigning right up to the debate and had been hospitalized for a knee infection that had left him with a 102-degree fever and looking pale and haggard, worsened by his notoriously heavy five o'clock shadow. Seventy million people watched the event. Millions more listened on the radio. According to a study published in the trade journal *Broadcasting,* those who saw the debate thought Kennedy won, whereas those who heard it gave Nixon the nod. For example, when *New York Herald Tribune* writer Earl Mazo first observed reactions to the debate at a conference, he observed, "Nixon was best on radio simply because his deep, resonant voice conveyed more conviction, command, and determination than Kennedy's higher-pitched voice and his Boston-Harvard accent. But on television, Kennedy looked sharper, more in control, more firm." These conclusions were replicated in a 2003 study in which subjects who viewed the debate were more likely to think Kennedy won than those who listened to it.

Why are we so influenced by such apparently trivial characteristics as voice and looks? In our evolutionary past they served as proxies for health, vigor and overall fitness (in both the physical and evolutionary sense). Such cognitive shortcuts remain necessary today because in a world abuzz with information overload, it isn't possible to rationally analyze all incoming data. So, on Election Day, try to override your predictably irrational propensity to succumb to these influences and engage your rational brain to vote the issues and not the person. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/oct2012

Illustration by Mark Jarman

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since Derek Jeter had a total of 12 base hits in the major leagues. He also hosts the *Scientific American* podcast Science Talk.

It's Full of Cats

Humanity's feline fixation extends to our electronic networks and gadgets

So many cats, so little time to worship each one.

I have just two cats. Well, "have" is a bit self-congratulatory. Let me put it this way: two cats have deigned to allow me the pleasure of their company in whatever manner they see fit. Each cat was abandoned by neighbors who moved and left the pet behind. (I know, right?) The first feline, long known to the children on the block as Patches, was already in the habit of visiting my house. So she simply made her visits much, much longer.

Cat two, Tigger, was also prenamed by the kids. I'd have gone with something grander, say, Athena and Achilles, but Patches and Tigger they were and will ever be. (Of course, we don't know and can never know their true, deep and inscrutable names.) When Tigger saw the sweet deal Patches got, he requested (okay, demanded) entry. At this moment, he is staring at me, which means he wants me to get out of *his* chair. I explain that I must needs sit here to work and thus keep him in cat food. His continued stare translates to: "Work when I don't need the chair, bub."

The Humane Society of the U.S. estimates that Americans own more than 86 million cats. And who can blame us? To have a tiny god, a Bastet, sitting on the sofa is a consummation to be devoutly wished for. (Dogs are great, too—they delivered the diphtheria antitoxin across the frozen tundra to Nome! Okay, dog people?)

The latest strong evidence of our cat fixation comes from an artificial-intelligence project at Google's X Labs. Researchers there put together a network of 16,000 computer processors, which were exposed to 10 million random YouTube videos. The network was then probed to see what it knew about the world. And when the researchers showed pictures of cats to the network, it basically responded, "Yes, I recognize that thing"—either because so much of what's on YouTube is cat-related or because Mr. Mistoffelees infiltrated the network and told it what was what.

Some news reports claimed that the researchers taught a computer to recognize cats, perhaps because Congress needs more faulty information to support cutting funding for scientific research. "The point wasn't to find a cat," Google research partner Andrew Ng of Stanford University told NPR. "It's just that cats [were] one thing we happened to look for and found," Ng then explained, based on his correct assumption that a lot of people post cat videos, and so the network saw lots of cats and learned to recognize them.

The bet here is that Ng also would have gotten a positive result had he asked the network if it recognized the image of a guy taking a projectile to the groinal area. Of course, a network trained to spot crotch smacks would not inspire Congress to support science funding, either. So here was the actual point: to observe how a small-scale simulated brain makes sense of the information to which it is exposed—which will come in handy for enterprises such as better search engines and speech recognition. Plus, there must be some connection to improved weapons systems. There, that ought to keep the money flowing.

Speaking of flowing money, some cat owners recently became quite cross with the company behind the iPad app Games for Cats. According to a Web site called the Escapist, the app entertains your cat by displaying various moving objects on the screen. It's a higher-tech version of making the cat chase a laser pointer's red dot, which is great exercise for the cat and a hilarious exercise for the human with the pointer.

Anyway, upgrades to the game were available for purchase via a menu. This menu was "so user friendly … that even cats can use it," according to the Escapist. After numerous allegedly inadvertent expenditures by cats, the app's designers complicated the menu pathway to ensure that only humans could buy more and better cat toys.

Must run, the little Bastet really wants the chair. SA

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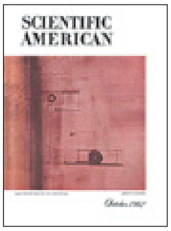
Comment on this article at ScientificAmerican.com/oct2012

Illustration by Matt Collins



October 1962

Crick on Coding

"The nucleic acids are made by joining up four kinds of nucleotide to form a polynucleotide chain. The chain provides a backbone from which four kinds of side group, known as bases, jut at regular intervals. The order of the bases, however, is not regular, and it is their precise sequence that is believed to carry the genetic message. The coding problem can thus be stated more explicitly as the problem of how the sequence of the four bases in the nucleic acid determines the sequence of the 20 amino acids in the protein. —F.H.C. Crick"

Crick shared the 1962 Nobel Prize in medicine for work he had done in 1953.

Cognitive Dissonance

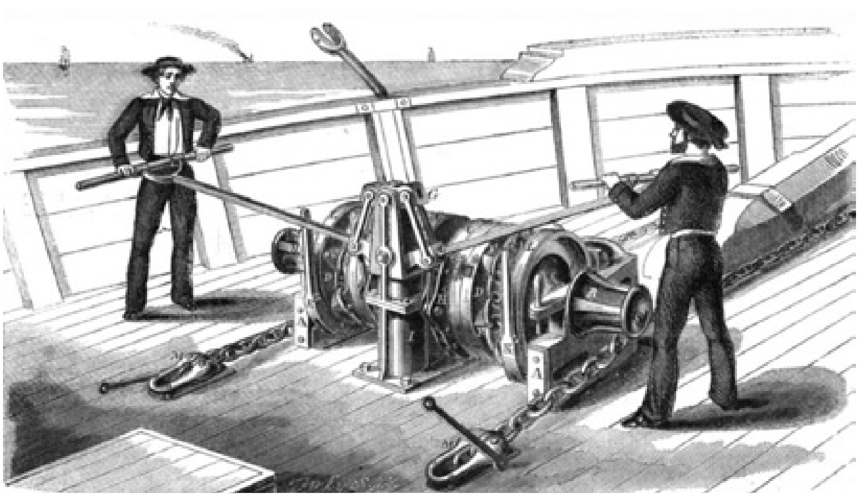
"Two items of information that psychologically do not fit together are said to be in a dissonant relation to each other. The items of information may be about behavior, feelings, opinions, things in the environment and so on. The word 'cognitive' simply emphasizes that the theory deals with relations among items of information. Such items can of course be changed. A person can change his opinion; he can change his behavior, thereby changing the information he has about it; he can even distort his perception and his information about the world around him. Changes in items of information that produce or restore consistency are referred to as dissonance-reducing changes. Cognitive dissonance is a motivating state of affairs. Just as hunger impels a person to eat, so does dissonance impel a person to change his opinions or his behavior. —Leon Festinger"

October 1912

Bacteria vs. Locusts

"A bacterial epidemic has within two years freed Yucatan of the locust swarms which periodically invaded the country. The malady lasts 12 to 46 hours and is characterized by a violent diarrhea, the contents of the bowels of the insects yielding a nearly pure microbe culture. The microbe has been isolated by M. Félix d'Hérelle, who in a memoir presented to the French Academy of Sciences examines its specific pathological effects. Now, M. d'Hérelle, having been asked by the Argentine government to test the effects of the same microbe on another locust species which every year devastates large portions of the Parana district, has reached surprisingly favorable results."

D'Hérelle's continued work on bacteria eventually led to his discovery of bacteriophages (viruses that infect bacteria) in 1917.

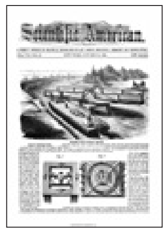


SAIL OR STEAM, sailors need to raise anchor before getting under way. This patent windlass makes the job faster, 1862

SCIENTIFIC AMERICAN, VOL. VII, NO. 15; OCTOBER 11, 1862

The Despised Horse

"The London *Daily Mirror* published a trenchant editorial on the foolishness of taxing automobiles for the use of city streets: 'The horse is a danger and a nuisance in the streets of a large city. We hear a lot of motor-car street taxes, but it is the horse which should be taxed, not the motor car. The horse is unhygienic, erratic and occupies too much space. Tax the horse as you would dogs, and leave the motor cars alone!' "



October 1862

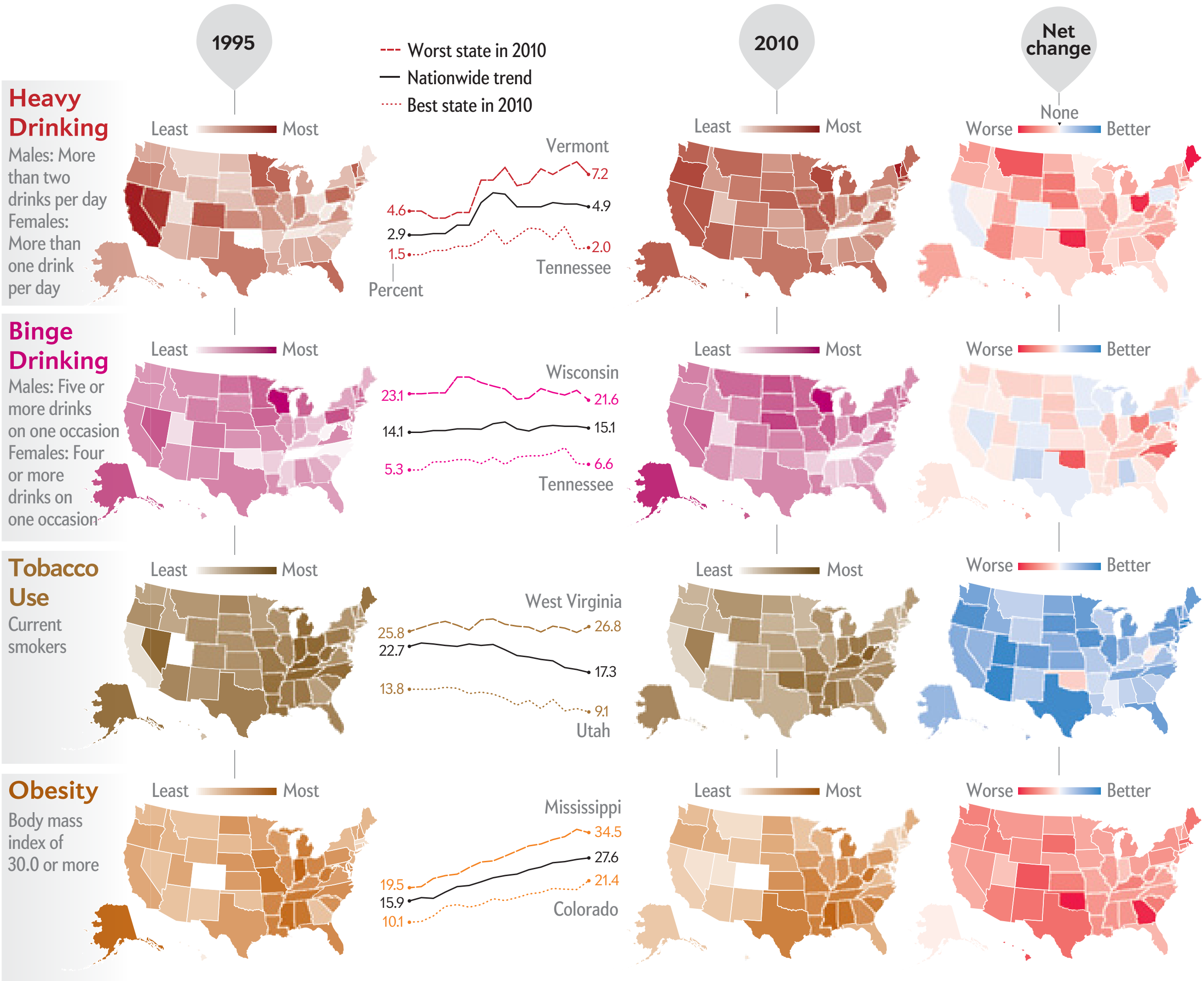
Anchors Aweigh

"The gearing of vessels by which the anchors are hoisted and let go, constitutes a very important mechanism for the safety and working of every ship that goes upon the 'mighty waters.' The accompanying engraving [*see illustration*] represents this gearing in different and improved forms."

Inventions Helping Farmers

"The report of the Superintendent of the Census for 1860 says: 'The greatest triumphs of mechanical skill, in its applications to agriculture, are witnessed in the instruments adapted to the tillage, harvesting and subsequent handling of the immense grain crops of the country, and particularly upon the Western prairies. Without the improvements in plows and other implements of tillage, which have been multiplied to an incredible extent, and are now apparently about to culminate in the steam plow, the wheat and corn crops of those fertile plains could not probably be raised. The reaping machine, the harvester and machines for thrashing, winnowing and cleaning wheat for the market, have become quite indispensable to every large grain grower.' "

View a slide show of agricultural technology from 1862 at www.ScientificAmerican.com/oct2012/agriculture



Fatter, Drunker Nation

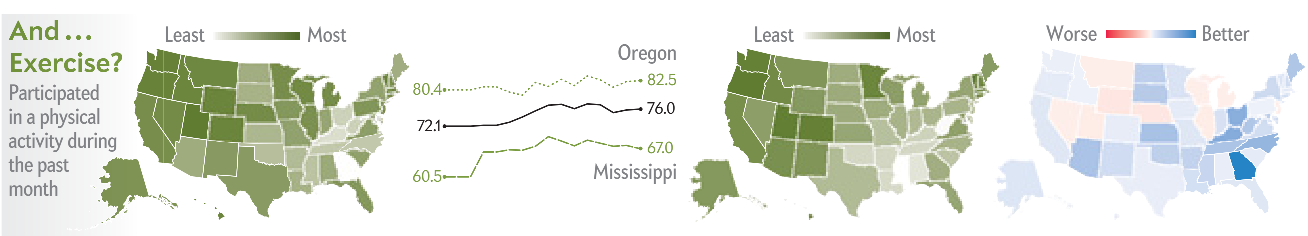
And yet Americans are smoking less and exercising more

Lost in the U.S. health care debate is whether the country's citizens are hurting themselves with bad habits. The bottom line is mixed, according to the Centers for Disease Control and Prevention. Americans are imbibing alcohol and overeating more yet are smoking less (*black lines in center graphs*).

Some of the behaviors have patterns; others do not. Obesity is heaviest in the Southeast (*2010 maps*). Smoking is concentrated there as well. Excess drinking is high in the Northeast.

Comparing 2010 and 1995 figures provides the greatest insight into trends (*maps, far right*). Heavy drinking has worsened in 47 states, and obesity has expanded in every state. Tobacco use has declined in all states except Oklahoma and West Virginia. The "good" habit, exercise, is up in many places—even in the Southeast, where it has lagged. —*Mark Fischetti*

SCIENTIFIC AMERICAN ONLINE
Full details for each state are available at ScientificAmerican.com/oct2012/graphic-science



SOURCE: BEHAVIORAL RISK FACTOR SURVEILLANCE SYSTEM SURVEY DATABASE, CENTERS FOR DISEASE CONTROL AND PREVENTION

Graphic by Pitch Interactive